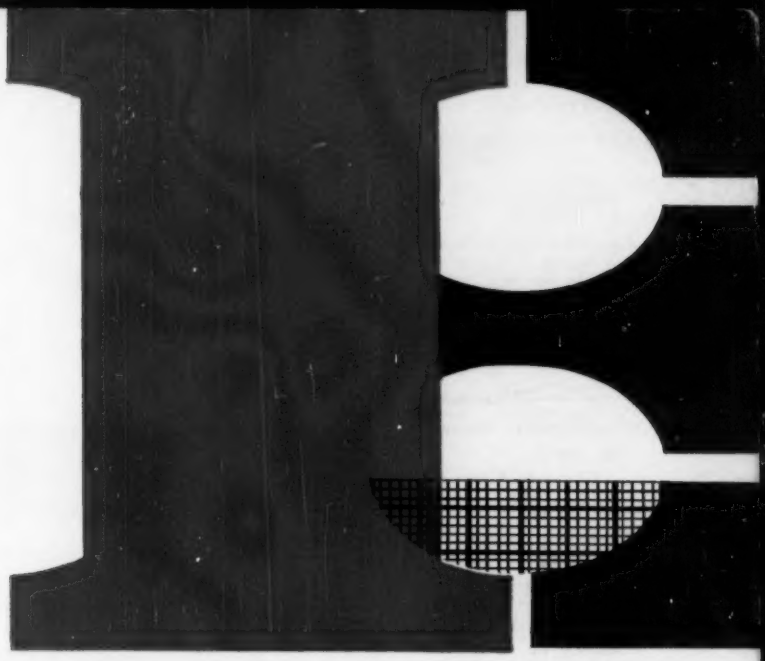


The Journal of INDUSTRIAL ENGINEERING

JULY—AUGUST 1961 VOLUME XII NUMBER 4

The Supreme Court and Arbitration
By Charles A. Werner 239

Operational Methodology for Evaluating Physiological Costs
By David C. Likey and Thomas J. Hall 243

Planning for Research in Management Control Systems—A Suggested Model
By Jay B. Hayne 253

Using Work Simplification in Research
By John S. Herrick 263

Information Content Analysis
By Donald K. Ross 267

SIMTAR, Automatic Electronic Motion Timer
By Stanley M. Elpar 276

Some Legal Aspects of Computer Use in Business and Industry
By Ray N. Freed 289

A Heuristic Method of Assembly Line Balancing
By Maurice O. Kilbridge and Leon Wester 292

President's Commencement Acceptance Speech as President of the American Institute of Industrial Engineers
By Jack F. Jericho 299

Recent Handbooks 302

Charter and Constitution Changes (Members Only) ..... Institute Interests 4

I.E. Opportunities Notice ..... Institute Interests 31

OFFICIAL PUBLICATION OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.

AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC

OFFICERS, 1961-1962

President
JACK F. JERICHO
United Air Lines

Executive Vice President
WILLIAM J. VALLETTE
Itek Laboratories

Vice Presidents
PROFESSIONAL SERVICES
MORLEY H. MATHEWSON
International Minerals & Chemical Corp.

PUBLICATIONS
ROBERT N. LEHRER
Northwestern University

REGION I
HENRY M. OWADES
Merck, Sharpe and Dohme Res. Labs.

REGION II
JOHN F. SWEERS
Fitchburg Paper Company

REGION III
SIDNEY T. NUTTING, JR.
Union Bag-Camp Paper Corporation

REGION IV
D. MILTON PITTS
Lockheed Aircraft Corporation

REGION V
ROGER M. SOTH
Hammermill Paper Corporation

REGION VI
RALPH F. FIX
Firestone Steel Products

REGION VII
JOSEPH W. COFFMAN
Army Ballistic Missile Agency

REGION VIII
JAY GOLDMAN
Washington University

REGION IX
TERRY S. LEARD
Hudgins, Thompson, Ball and Associates

REGION X
C. WILSON WHITSTON
University of Southern California

Treasurer
WILLIAM K. HODSON
H. B. Maynard and Company

Executive Secretary
E. PAUL LANGE
AIIE, New York

Board Members-at-Large
HERBERT ASHCROFT, JR.
Bausch and Lomb Optical Co.

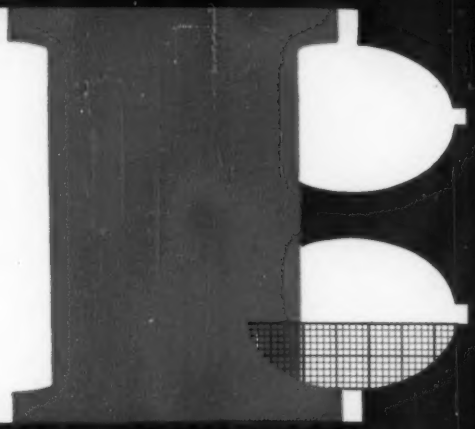
GEORGE H. GUSTAT
Eastman Kodak Company

ROBERT H. ROY
The Johns Hopkins University

HARRY L. DAVIS
Eastman Kodak Company

Past Presidents
ALEX W. RATHE (13)
FRANK J. JOHNSON (12)
GEORGE H. GUSTAT (11)
GORDON B. CARSON (10)
HOWARD P. EMERSON (9)
EDWARD L. SLAGLE (8)
DONALD G. MALCOLM (7)
FRANK F. GROSECLOSE (6)
MATTHEW A. PAYNE (5)
JOHN D COLEMAN (4)
ROBERT E. ALLEN (3)
DWIGHT D. GARDNER (2)
ELDON D. RANEY (1)

Founder
WYLLYS G. STANTON



The Journal of **INDUSTRIAL ENGINEERING**

OFFICIAL PUBLICATION OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.

EDITORIAL STAFF

Editor-in-Chief
ROBERT N. LEHRER
The Technological Institute
Northwestern University

Editor
CECIL G. JOHNSON
Georgia Institute of Technology

Associate Editors
TEE H. HIETT
Georgia Institute of Technology

JACK R. WALKER
Georgia Institute of Technology

News Editor
WILSON J. BENTLEY
Oklahoma State University

Recent Readables Editor
J. KENNETH LEGLEU
Ethyl Corporation

Assistant Editor
WILLIAM W. HINES
Georgia Institute of Technology

Editorial and Administrative Assistant
EMMA B. DONNELLY
Journal of Industrial Engineering

EDITORIAL BOARD

FRANK F. GROSECLOSE, *Chrmn.*
Georgia Institute of Technology
JOHN M. ALLDERIGE
Cornell University
ALBERT B. BISHOP, III
Ohio State University
RICHARD G. CANNING
Consultant
HAROLD O. DAVIDSON
Operations Research, Incorporated
DANIEL J. DUFFY
Polytechnic Institute of Brooklyn
JOHN W. ENELL
American Management Association
RICHARD A. FORBERG
The Procter and Gamble Company
HERBERT J. GROELINGER
Operations Research, Incorporated
BRUCE M. JOHNSON
Northwestern University
MAURICE D. KILBRIDGE
University of Chicago
ALAN J. LEVY
Management Consultant
ROBERT W. LLEWELLYN
North Carolina State College
DONALD G. MALCOLM
Operations Research, Incorporated
JOSEPH J. MODER
Georgia Institute of Technology
WILLIAM T. MORRIS
Ohio State University
JAMES A. RICHARDSON
Eastman Kodak Company
ALAN J. ROWE
Hughes Aircraft Company
ROBERT H. ROY
The Johns Hopkins University
ANDREW SCHULTZ, JR.
Cornell University
HAROLD E. SMALLEY
Georgia Institute of Technology
AUSTIN WESTON
Times-Mirror Press

Published Bimonthly **• American Institute of Industrial Engineers, 32 West Fortieth Street, New York 18, New York •** ***Editorial Offices*****—A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia**

Copyright 1961 by The American Institute of Industrial Engineers, Inc. Reprint permission available from the Editorial Offices.

AIIE accepts no responsibility in connection with any liability which might develop as a result of articles published, for the opinions expressed are those of the authors and do not necessarily represent the Institute.

Subscription Prices: $10.00, one year; $17.00, two years; single issue, $2.50. (Special issues available at additional cost.)

All Manuscripts for review should be submitted with drawings suitable for reproduction to the Editor-in-Chief, Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia.

Advertising Rates available from Editorial Offices. Send copy and cuts to Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia.

Membership Information available from AIIE.

Change of Address notification should be submitted to American Institute of Industrial Engineers, 32 W. Fortieth Street, New York 18, New York.

► **All issues of the *Journal of Industrial Engineering* are now available on microfilm or Xerox copy to subscribers through University Microfilms, 313 N. First Street, Ann Arbor, Michigan.**

Second-class postage paid at New York, New York and at additional mailing offices.

The Supreme Court and Arbitration

by **CHARLES A. WERNER**[1]

Attorney, Schuchat and Cook

ON JUNE 20, 1960, the United States Supreme Court handed down three sweeping decisions which drastically limited the power of federal courts in deciding questions of arbitrability under Section 301 of the Taft-Hartley Act. On the issue of enforcing or denying arbitration awards the Court broadened the authority of the arbitrator by holding that opinions need not be free from ambiguity, nor did the arbitrator have any obligation to the court to give his reasons for the award.

Concurrent with the aforementioned determination of the specific issues presented to it, the Court commented on the whole scope of labor relations—arbitrations, collective bargaining agreements, management rights, etc. It noted the existence of an industrial common law (the practices of the industry and the shop) which it said constituted a part of the collective bargaining agreement though not expressed in the agreement. It recognized that the processing of even frivolous claims may have therapeutic value, and consequently courts should not exclude grievances from arbitration unless it can be said with "positive assurance" that the dispute is not arbitrable. Any doubts should be resolved in favor of arbitrability. The court reasoned that the "processing of disputes through the grievance machinery is actually a vehicle by which meaning and content are given to the collective bargaining agreement."

This brief introduction to *Steelworkers versus American Manufacturing Company*, 363 U.S. 564, *Steelworkers versus Warrior and Gulf Navigation Company*, 363 U.S. 574, and *Steelworkers versus Enterprise Wheel and Car Company*, 363 U.S. 593, should convince the reader of the potential impact that these decisions may have upon the industrial scene. Not enough time has passed as yet to fully appreciate or know what the real effect of the decisions will be. However, one fact can be stated—the decisions have generated considerable discussion and debate during the past year.

There are some people who believe that the decisions strike a crippling blow to the heretofore sacred right of management to run its business as it chooses, subject only to those rights which it bargains or gives away to the unions. Now, they say, the philosophy is diametrically reversed. Unless the collective bargaining agreement specifically excludes an action of management from the grievance and arbitration clause, the propriety of that action is subject to arbitration. Other labor relations personnel worry about the apotheosis afforded arbitrators by the Court. They argue that arbitrators are already too powerful, and with the checks and balances of the courts removed, the arbitrator will begin to issue "legislative type" awards which stray far from the issues presented to him.

There are many, however, who maintain that the decisions correctly state the present role of arbitration in industry today. They accept the therapeutic value of letting off steam by means of the grievance-arbitration process, and predict that the decisions will put an end to the harmful trend of management running to the courts and claiming that a dispute is frivolous or lacks merit, or that an unfavorable award should be set aside. If such a trend had continued to grow, they contend, unions would have substituted the strike in place of arbitration, because judicial intervention means only delay, expense and frustration.

While union leaders, top management and labor relations personnel have been the main participants in the discussions thus far, it is obvious that all persons working in a plant which has a grievance-arbitration clause in the collective bargaining agreement should have an understanding of the basic issues involved. It does not matter whether a person's activities are directly or indirectly related to the agreement, such as an incentive system tied into the agreement or a management established standards control. What is important, is that the activities involve some phase of working conditions which could develop into a labor dispute. Such a dispute, unless specifically excluded from the aforesaid grievance-arbitration process, would be subject to it.

The rest of this article concerns a review of Section 301 of the Taft-Hartley Act and the three Supreme Court decisions. In addition, several court decisions involving Industrial Engineering activities are cited, since it is this author's opinion that Industrial Engineers should participate more actively in the collective bargaining picture (1).

BACKGROUND OF DECISIONS

In 1947, Section 301 was added to the Labor Management Relations Act (commonly referred to as the Taft-Hartley Act):

> (a) Suits for violation of contracts between an employer and a labor organization representing employees in an industry affecting commerce as defined in this Act, or between any such labor organizations, may be brought in any district court of the United States having jurisdiction of the parties, without respect to the amount in controversy or without regard to the citizenship of the parties.

[1] The author is a graduate Industrial Engineer and teaches a course entitled "Industrial Engineer and Labor" in the Department of Industrial Engineering, Washington University.

This section permitted a union, representing employees in an industry affecting commerce, to sue in behalf of the employees for violations of collective agreements, and conversely, to be sued by employers. Prior to the enactment of this section, it was difficult to sue and recover judgments against unions because the greater majority of unions are unincorporated associations, and consequently, involved procedural questions were raised every time court action was sought. With enactment of this section, suits could be brought in the federal district court having jurisdiction of the parties, regardless of diversity of citizenship or federal jurisdictional amount.

However, it wasn't until the landmark case, *Textile Workers Union versus Lincoln Mills of Alabama,* 353 U.S. 448 (1957) that unions and management became aware of the fact that Section 301 was to usher in a new era in the field of labor relations. In that case, the United States Supreme Court held that *federal district courts* under Section 301 *had the authority to fashion a body of federal law for the enforcement of collective bargaining agreements.* Included therein was the authority to compel arbitration by ordering specific performance of the arbitration clauses in contracts. The Supreme Court reasoned that by adopting Section 301, Congress was interested in promoting collective bargaining contracts which included promises to arbitrate grievances instead of going out on strike. "Plainly the agreement to arbitrate grievance disputes is the quid pro quo for an agreement not to strike," the Court said. Viewed in this light, the legislation did more than confer jurisdiction in the federal courts over labor organizations. It expressed a federal policy that federal courts should enforce these agreements on behalf of or against labor organizations, and that industrial peace can best be obtained only in that way. The Court then said that the substantive law which is to be applied in these suits is federal law, which the courts must fashion from the policy of our national labor laws.

The task of fashioning a body of substantive law to apply in enforcing the arbitration provisions of contracts and the general contract violations was not a simple matter for the federal courts to undertake. While the Supreme Court in Lincoln Mills formulated certain guideposts, there developed during the succeeding three years a divergence of opinion as to the role of the federal courts in the relationship between unions and management. It was at this point that the Supreme Court stepped in, granted certiorari in the aforementioned cases, and by its decisions "attempted" to determine the relative positions of the federal courts, arbitrators, and the collective bargaining agreement. The Court held that the federal district court should enforce the arbitration provision of the contract unless the contract specifically excludes the grievance from arbitration, that the courts are not to look beyond arbitrability and into the merits of the case, and that the courts should not review the arbitrator's award unless "the arbitrator's words manifest an infidelity to" his obligation.

THE THREE DECISIONS

In *Steelworkers versus American Manufacturing Company,* supra, the Union filed suit in the federal district court to compel arbitration of a grievance which alleged that an employee, who had been off work because of an injury on the job, was entitled to return to his job by virtue of the seniority provision of the contract. The employer refused to arbitrate the grievance because:

1. The employee a few days previously had settled a workmen's compensation claim against the employer on the basis that he had a permanent partial disability.
2. That he was not physically able to do the work.
3. That this type of dispute was not arbitrable under the collective bargaining agreement in question.

The agreement provided:

> Any disputes, misunderstandings, differences or grievances arising between the parties as to the meaning, interpretation and application of the provisions of this agreement, which are not adjusted as herein provided, may be submitted to the Board of Arbitration for decision.

The district court held that the employee was estopped to claim any seniority because of his acceptance of the permanent partial disability, and granted the employer summary judgment. The Court of Appeals affirmed on the ground that the grievance was "a frivolous, patently baseless one, not subject to arbitration under the collective bargaining agreement."

The Supreme Court reversed the lower courts and held that the grievance was arbitrable. It held that the function of the federal court is confined to ascertaining whether the party seeking arbitration is making a claim which on its face is governed by the contract. It stated:

> Whether the moving party is right or wrong is a question of contract interpretation for the arbitrator. In these circumstances the moving party should not be deprived of the arbitrator's judgment, when it was his judgment and all that it connotes that was bargained for.
>
> The courts therefore have no business weighing the merits of the grievance, considering whether there is equity in a particular claim, or determining whether there is particular language in the written instrument which will support the claim. The agreement is to submit all grievances to arbitration, not merely those the court will deem meritorious. The processing of even frivolous claims may have therapeutic values which those who are not a part of the plant environment may be quite unaware.

Justice Douglas said at the end of his decision that:

> When the judiciary undertakes to determine the merits of a grievance under the guise of interpreting the grievance procedure of a collective bargaining agreement, it usurps a function which under that regime is entrusted to the arbitration tribunal.

The second case, *Steelworkers versus Warrior and Gulf Navigation Company,* supra, involved the issue of management rights, specifically the question of whether the contracting-out of work violated the collective bar-

gaining agreement. The union charged that the employer from 1956-1958 had reduced the bargaining unit from 42 to 23 men, and that the reduction was due in part to the contracting-out of maintenance work to other companies. When the employer refused to arbitrate the grievance, the union brought suit in the federal district court to compel arbitration.

The district court granted the employer's motion to dismiss holding that the contracting-out of repair and maintenance work, as well as construction work, was strictly a function of management not limited to any respect by the labor agreement in question. The agreement between the parties had both a "no strike" and a "no lockout" provision, it had an arbitration clause calling for arbitration of disputes "as to the meaning and application of the provisions of this agreement," and it also had a clause which provided that "matters which are strictly a function of management shall not be subject to arbitration." The Court of Appeals affirmed the lower court's decision and the Supreme Court granted certiorari.

In a 7-1 decision, the Supreme Court reversed the lower courts and held that the dispute was arbitrable. The Court said that "apart from matters that the parties specifically exclude, all of the questions on which the parties disagree must therefore come within the scope of the grievance and arbitration provisions of the collective agreement." It said that the grievance is a part of the continuous bargaining process, and it, rather than a strike, is the terminal point of a disagreement. The Court commented that collective agreements, unlike commercial contracts, are never complete, and that the parties adopt arbitaration as a means of filling in the gaps—adding new terms to cover unforeseen matters.

In determining the arbitrability of an issue, the Court stated, "doubts should be resolved in favor of coverage," and an order to arbitrate "should not be denied unless it may be said with positive assurance that the arbitration clause is not susceptible to an interpretation that covers the asserted dispute." The Court then stated that it did not agree with the lower courts that contracting-out was necessarily excepted from the grievance procedure of this agreement by the clause "strictly a function of management." If courts in order to determine arbitrability were allowed to determine what is permitted and what is not, then the aforesaid generalized exception would swallow up the arbitration clause. Therefore, in the absence of any express provision excluding a particular grievance from arbitration, it is arbitrable. Particularly is this true where, as in the agreement in question, the exclusion clause was vague and the arbitration clause broad. The Court concluded that the question of contracting-out presented a question as to the interpretation of the contract and was subject to arbitration.[2]

[2] At the time of writing this article the question has been arbitrated, but the arbitrator has not issued his decision as yet.

In the third case, *Steelworkers versus Enterprise Wheel and Car Corporation*, supra, the union sought enforcement of an arbitration award wherein the arbitrator had held that the employer should reinstate a group of discharged employees and give them back pay minus a 10 day penalty period. The employer contested the award contending that during the period between the discharges and the arbitration the collective bargaining agreement had expired, therefore, it did not have to reinstate the employees or pay them back pay. The district court granted enforcement, but the Court of Appeals modified the award stating that an award for back pay and for reinstatement subsequent to the date of termination of the agreement could not be enforced.

Again, reversing the Court of Appeals, the Supreme Court ordered that the award should be enforced (subject to the modification that the amounts due the employees should be definitely determined). The Court stressed the fact that the parties had bargained for the arbitrator's construction of the contract, and that the lower court had no business overruling him because its interpretation of the contract was different from his. The Court stated that if the arbitrator's award manifested an infidelity to his obligation then the court had no choice but to refuse enforcement. But, such was not the case where the award was merely ambiguous. The Court said that "a mere ambiguity in the opinion accompanying an award, which permits the inference that the arbitrator may have exceeded his authority, is not a reason for refusing to enforce the award. Arbitrators have no obligation to the court to give their reasons for an award." The Court added that if arbitrators had to be free of ambiguity, that arbitrators would then play it safe by writing no supporting opinions. This, the Court said, "would be undesirable for a well reasoned opinion tends to engender confidence in the integrity of the process and aids in clarifying the underlying agreement."

DISPUTES INVOLVING INDUSTRIAL ENGINEERING ACTIVITIES

The effect of the Supreme Court decision on disputes involving Industrial Engineering activities will probably be that unless the disputes are specifically excluded from the grievance and arbitration process (assuming that the parties have agreed in their contract to arbitrate their differences) they will henceforth be arbitrable. Whereas in the past management maintained that the arbitration of wage and incentive disputes had the effect of reopening the contract for wage negotiations (and perhaps a truthful argument), such disputes in the future may be taken to arbitration if not resolved by the parties. Thus, management action, whether it be in the form of contracting-out or issuing a piece work rate, is now subject to far wider review than in the past. Unless such disputes are specifically excluded, unions will be able to

challenge the propriety of management's action through the means of arbitration.

It has already been proposed that the aforementioned problem can be obviated by inserting in the contract a clause which states that all wage and incentive disputes are not subject to the grievance and arbitration process. However, while such a clause would prevent the problem from arising, the chances of obtaining such a clause may be realistically stated as being quite slender. A more realistic approach is that unions and management might agree on specifying certain areas which would be subject to the grievance and arbitration process, and certain areas which would be excluded. Restrictive language added to the contract clarifying the areas of potential friction will aid both management and unions in administering a contract, which while permitting review of management's action would channel that review to a constructive and workable relationship.

Even this limited approach may be difficult to achieve, and if achieved, may not work out as planned. In (1) the 1959 case, *IUE versus Westinghouse*, 268 F. 2d 352, 44LRRM 2369 (3rd Cir.) was cited to illustrate the difficulties involved in attempting to limit incentive arbitrations. In that case, which was decided prior to the aforementioned three Supreme Court decisions, the Court held that the limitations in the contract did not limit the determination as to whether or not there was an *existing time value* for the particular operation. The Court reasoned that the arbitrator would "be merely declaring what the particular actual time value situations are by correct interpretation of the existing written collective bargaining agreement," and would "neither be establishing new time values or modifying the present ones." Unless changes are made in collective bargaining agreements, the above result will be repeated many times in the future.

Since the Supreme Court decisions, there has been only one arbitration concerning Industrial Engineering activities which has been involved in a reported court proceeding. In that case, *Local 791, IUE versus Magnavox Company*, F.2d—47 LRRM 2572 (6th Cir., 1961), the Court held that the arbitrator had exceeded his authority when he directed the parties to enter into negotiations concerning engineering studies relating to production speeds on the assembly line. The union had originally filed a grievance that the employer had increased the speed of the assembly line in the speaker department and thereby demanded that the operators produce more work. The union requested that the speaker lines be put back to their regular speeds. The dispute was taken to arbitration where the arbitrator held that it was arbitrable. The parties then proceeded into the merits of the case, and upon completion of the hearing, the arbitrator dismissed the grievance. However, in his award he directed that the union and the employer enter into negotiations concerning the production line speeds after additional engineering surveys and studies on the assembly line were carried out. The contract between the parties specifically limited the function of the arbitrator. It provided:

> The function of the Arbitrator shall be of a judicial rather then a legislative nature. He shall not have the power to add to, to ignore, or modify any of the terms and conditions of this Contract. His decision shall not go beyond what is necessary for the interpretation and application of this Contract, or the obligation of the parties under this Contract. No decision shall decide issues not directly involved in the case.

The Court of Appeals held that when the arbitrator dismissed the grievance on the ground that the union did not prove that the company increased the speed of the assembly lines, his function ended insofar as the grievance was concerned, and insofar as the provisions of the contract provided for his arbitration. The Court went on to say that "nothing in the contract empowered him to direct that the company and the union enter into negotiations concerning engineering surveys and studies relating to the speed of the production line. To do this, he would be obliged to add to the terms of the contract" and beyond the powers conferred on him by the collective bargaining agreement. The union maintained that the Court's decision was in conflict with the *American Manufacturing Company, Warrior and Gulf Navigation*, and *Enterprise Wheel and Car Company* cases. The Court disagreed, stating that the foregoing cases were completely different than the one before it. In the case at bar, the issue before the arbitrator was dismissed by him, and his function at that point ended.

CONCLUSION

The Supreme Court arbitration decisions are typical of the related material which Industrial Engineers must become familiar with to mold the type of work product which achieves maximum effectiveness. It is readily apparent that a proficiency in setting rates or performing some other task is generally not sufficient in and of itself. As the National Labor Relations Board, the courts, and arbitrators become a more vital force on the industrial scene, it is incumbent upon the Industrial Engineer to understand the interrelationships of these bodies and their effect upon collective bargaining agreements and labor relations in general. The awareness necessary to produce an effective work product includes an appreciation of the fact that the most effective work product is one which is built upon a solid foundation, and includes sufficient controls to channel the effort from start to finish and to minimize disruptive forces. It is hoped that this article will assist the Industrial Engineer in acquiring the aforesaid necessary awareness.

REFERENCE

(1) Werner, Charles A., "Industrial Engineers, Incentive Systems, and the Contract," *Journal of Industrial Engineering*, May-June 1960, pp. 231-236.

Operational Methodology for Evaluating Physiological Costs

by **DAVID C. EKEY**

Professor of Industrial Engineering, Georgia Institute of Technology

and **THOMAS J. HALL**

Instructor in Industrial Engineering, Georgia Institute of Technology

THIS REPORT represents preliminary research activity in a proposed long-range program to study human energy expenditures in industrial operations. The motivation is that of providing a fund of knowledge which will permit the Industrial Engineer to improve his decision activities relative to:

1. The realistic measure of a "fair day's work."
2. Man's physiological capacity for work in various industrial environments.
3. The proper base upon which to establish remuneration for physical effort.
4. Optimization of the work schedule to decrease operator fatigue and increase operator productivity over time.

Wage incentives, job evaluation, methods analysis, time study, production control, plant design, and "man-machine" systems design and analysis are functions of the Industrial Engineer which require a fundamental understanding of human energy expenditures. Progressive union-management relations require constant refinement and re-evaluation of these functions.

One of the least defensible Industrial Engineering procedures is the application of subjective ratings and allowances to physiological work. This subjectivity creates disturbing situations in many instances; situations due, not only to the relative indefensibility of any designated allowance, but in many more cases to inherent weaknesses in the particular methods of determining and applying the allowances. Thus, the Industrial Engineer, realizing that he must justify his time standard, is forced into the position of having to re-examine thoroughly his methods of determining and applying allowances.

Is the amount of personal rest allowance that permits the worker to maintain the apparent optimum productivity rate sufficient to prevent undue fatigue? Consider the following quotation from Viteles (17):

> For every type of work there exists an optimal speed which will make it possible to get as much as possible done with the least expenditure of energy and without increasing the feelings of fatigue, discomfort and ill health. The determination of these speeds, from the viewpoint of human efficiency, is almost an untouched field. They have been fixed again and again, for many types of work, with respect to the highest rate or amount of production, but there is reason for believing that this rate often conflicts with the optimum welfare of the worker.

There is no doubt that higher standards of living, social security, shorter working hours, improved safety standards, better hygiene and medical care have improved the life of the modern worker. Nevertheless (6):

> Management, unaware of the importance of human physiology and interested only in the fact that a worker is good, mediocre or bad as far as productivity is concerned, does not realize that it would lead to major industrial and social progress to know the physiological reactions of the individual on the job.

The physiological approach in work study has always been attractive since the fatigue allowances and performance rating occupy such a dominant position in the make-up of an industrial time standard. Engineers cannot adequately evaluate the functional characteristics of a machine on the exclusive basis of a stop watch analysis. It is equally impossible to adequately evaluate the functional capacity of the human machine by the same methods since the stop watch procedure is inherently unable to measure the physiological cost of a job.

Industrial Engineers establish their concept of normal performance for a particular operation by estimating the speed at which the effort required to perform the operation appears normal. Some engineers have a standard concept of effort, namely a man walking unburdened on level ground at three miles per hour, which they use as a yardstick. Others carry as a mental concept, a pattern of all the various normal rates (?) they have previously established.

From the pragmatic viewpoint one must agree that these so-called "scientific" methods are operational, but we know they yield only rough approximations to the basic problems of: what constitutes a fair day's work for a given population of workers; what constitutes the optimum pattern of rest periods for a given job; what effect the environmental factors of heat, humidity, and

FIGURE 1. Operation of the Bicycle Ergometer.

work load have on human energy expenditures; how to rank the physical effort factor among jobs in job evaluation work; and, whether or not the present approximations of increased productivity to wage incentives accurately relate the additional human energy requirements.

Considerable research effort has been expended over the years in this field, but unfortunately most of this work has been directed toward refinement and defense of the original concepts of time and motion study. The minute scope of the research leaves unsolved the question of how to attain accurate measurements relative to the human energy factor. Work and rest standards as they now exist are more or less arbitrary. They do not adequately take into account the efficiency and the power of the worker's muscles, heart and lungs; they do not necessarily represent the time needed to perform an operation with a minimum physiological cost and a maximum human efficiency of production. They represent even less the rest time needed by workers to insure an adequate recovery between successive operations. The physiological cost of jobs should be measured and kept within reasonable limits because it is the only accurate means of determining the physical component of human effort.

Numerous experiments have been performed to study the physiological effects of muscular work of varying degrees of intensity (9) (16) (19). It is known that, when shifting from a resting condition to one of physical activity, many physiological functions change from their resting level to a working level (5). Heart rate, blood pressure, cardiac output, pulmonary ventilation, oxygen consumption, chemical composition of the blood and urine, body temperature, and rate of sweating are all modified by muscular activity.[1]

[1] See Appendix for review of pertinent literature.

EXPERIMENTAL PROCEDURE

To evaluate selected physiological variables, characterized by adaptability to noncomplex measurement and recording procedures, during both rest and work increments of task cycles, it was necessary to design standard tasks involving a wide range of physical effort. The operational criteria were:

1. The physiological variables must accurately correlate with physical effort expended over time.
2. The related measuring equipment must not burden or restrict the subject's activities.
3. Ultimately, the variable(s) must be capable of detection and subsequent wireless transmission from the subject to recorders (e.g., meters) in varied industrial environments.

Two standard tasks, each at two rates, involving upper and lower body muscle groups respectively, were utilized. Six physiological factors, measured while subjects performed the two standard tasks, were analyzed by the analysis of variance technique.

Ten male college students were selected at random from a stratified population (a Georgia Tech fraternity group of sixty students) to perform standard tasks on a bicycle ergometer (Figure 1) and a torsion bar ergometer (Figure 2).

These subjects were selected on a basis of willingness of the entire fraternity group to participate. No formal individual or group motivation was introduced. As a further qualification the subjects had all previously passed the Georgia Tech physical fitness tests and had participated in the physical education program required of all students at the school.

The experiment was divided into two distinct split-

FIGURE 2. Operational Setup of the Torsion Bar Ergometer.

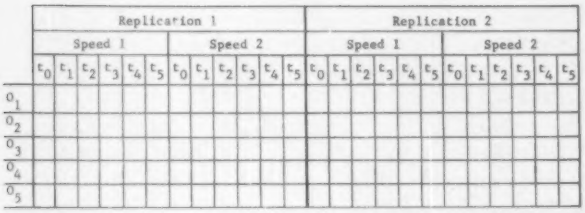


FIGURE 3. Experimental Design.

plot designs of the form shown in Figure 3; five subjects were randomly assigned to the torsion bar task and five to the cycling task.

The cycling task utilized a constant brake load and the subject was required to maintain by visual observation tachometer readings of 18 revolutions per minute (slow speed), and 36 revolutions per minute (high speed). Effective energy outputs at these speeds (strenuous exercise) were calculated to be 0.064 horsepower and 0.128 horsepower respectively. The torsion bar task utilized a constant torque load and the subject was required to maintain by visual observation of a metronome, uniform stroke rates of 50 per minute, and 100 per minute. Effective energy outputs at these rates (mild exercise) were 0.023 horsepower and 0.046 horsepower respectively.

At each task level the subject was required to perform five three-minute increments of work uniformly interspersed by six three-minute rest periods for a total elapsed cycle time of 33 minutes. A continuous trace of the subject's heart rate and heart sound was recorded throughout the entire 33 minutes. Blood pressure components and galvanic skin response (GSR) were recorded intermittently; GSR at the beginning and end of all work and rest increments, but blood pressure only at the end of each work increment. This recording procedure yielded a reference reading and five progressive work and rest readings for each of the six dependent physiological variables (i.e., heart rate, heart sound, galvanic skin response, systolic blood pressure, diastolic blood pressure and pulse pressure). Concomitant variables, observed and recorded for possible future analysis, were: room temperature, relative humidity, time of day, the subject's height, age, weight, weight-to-height ratio and relative physical fitness.

The experiments were conducted during the month of May, 1960, with unseasonably high temperatures occurring during the afternoon recording periods. Dry-bulb temperature, recorded at the beginning and end of each task period, ranged from a high of 93°F. to a low of 74°F. Relative humidity, recorded concurrently with temperature ranged from 70.0 to 42.0 percent. Task periods were scheduled, Monday through Saturday, between 8:00 A.M. and 6:00 P.M. An attempt was made to randomize time of day of task performance but this was, of course, influenced by the subject's class schedule. Table 1 shows concomitant data of subjects.

The experimentation was conducted in a classroom of Georgia Tech's School of Industrial Engineering approximately 20 feet wide by 30 feet in length. Cross ventilation was provided by a door transom, four window transoms, and two double-casement windows, which were kept open at all times. The one double door was kept closed while a task performance was in progress although subjects not under observation were permitted to enter or leave at their convenience. The noise level was approximately that of a normal classroom since classes were being conducted in adjacent areas of the building. Lighting was provided by fluorescent fixtures and indirect sunlight.

Prior to experimentation all subjects were called into the laboratory for orientation. They were instructed on the general nature of the experiment but not on the specific measurements, objectives or hypothesized results. Each subject was given a prearranged schedule of his performance times and instructed to bring gym shorts and hard soled shoes to the laboratory. Subjects were stripped to the waist when working, and were not permitted to work within one hour after eating.

According to the preassigned times the subject arrived at the laboratory at the beginning of the hour. Other subjects were permitted to attend and observe in a non-participating capacity if they so desired. The subject was rested while seated for a minimum of ten minutes and questioned as to his activities of the previous 24 hours. He then assumed a standard position at the task device to which he was assigned. A blood pressure cuff was taped to the subject's upper left arm so that it was in position throughout the task period. Electrodes for the GSR and cardiotachometer were placed on the hands and chest of the subject and a heart sound microphone placed over the apex of the heart.

Proper function of the recording equipment was checked, and then the subject was told which speed he

TABLE 1

Subject Concomitant Data

Male Subjects	Age	Height	Weight	Wgt/Hgt	Physical Fitness
O_{1b}	20	71 in.	145 lbs.	2.02 lbs./in.	0
O_{2b}	18	73 in.	180 lbs.	2.47 lbs./in.	1
O_{3b}	17	74 in.	155 lbs.	2.09 lbs./in.	1
O_{4b}	19	72 in.	175 lbs.	2.43 lbs./in.	1
O_{5b}	20	76 in.	170 lbs.	2.24 lbs./in.	0
O_{1t}	19	70 in.	185 lbs.	2.64 lbs./in.	1
O_{2t}	21	72 in.	153 lbs.	2.12 lbs./in.	0
O_{3t}	18	66 in.	150 lbs.	2.27 lbs./in.	0
O_{4t}	28	74 in.	190 lbs.	2.57 lbs./in.	0
O_{5t}	20	70 in.	165 lbs.	2.36 lbs./in.	0

$_b$ = bicycle ergometer.
$_t$ = torsion bar ergometer.
0 = average.
1 = above average.

was expected to maintain. Following the recording procedure outlined previously the subject completed a 33 minute task cycle of intermittent work and rest.

After the five subjects had completed two levels for a given task the experiment was replicated with the order of task performance again randomized. Task performances were scheduled with the restriction that no subject would perform more than one task cycle within the same 24 hour period.

ANALYSIS AND RESULTS

During the experimentation two subjects "O_{15}" and "O_{55}" became exhausted due to excessive heat and were unable to complete the second replication of strenuous exercise at "high speed." Consequently this part of the experimental design was broken down into two separate designs, neither of which utilized the portion of the second replication containing the missing data points. The first of these designs consisted of first replication data for all subjects. The second design consisted of data from both replications for three subjects. The single replication design is not discussed since the results compared favorably with those of the twice replicated, three-subject design. An analysis of variance for both parts of the experiment yielded significant sources of variation as shown in Table 2.

The time effect was found to be the most significant source of variation in all phases of the experiment. It was found to be significant at the one percent level for all six dependent variables, except one, for both tasks at work and at rest. The one exception was the effect of time on blood pressure at mild exercise; however, this result is suspect. The task level effect and operator effect were significant over time. The task level consistently interacted with time at various degrees of sensitivity among the dependent variables and tasks. The operator effect was consistent to a lesser degree as indicated in Table 2.

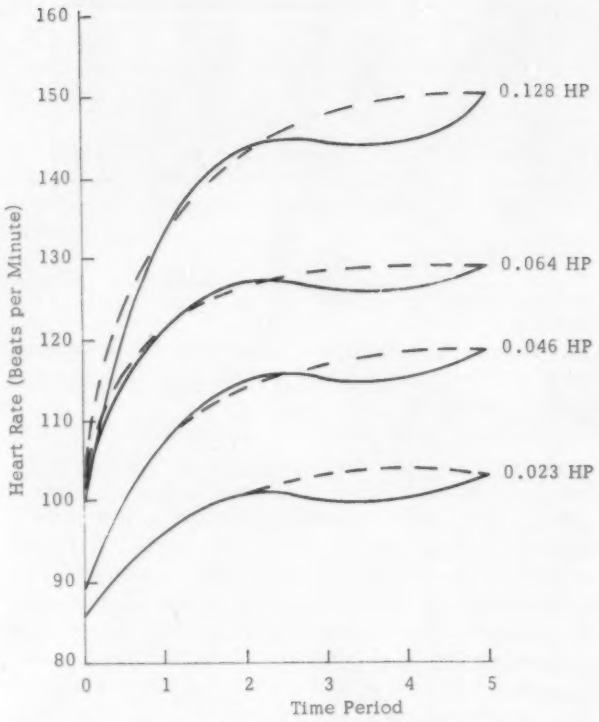


FIGURE 4. The Effect of Cumulative Work Time on Heart Rate at Four Different Levels of Energy Expenditure.

TABLE 2

Significant Sources of Variation

Dependent Variable	Significance Level	Strenuous Exercise 0.64 HP to 1.28 HP		Mild Exercise 0.23 HP to 0.46 HP	
		Work*	Rest*	Work**	Rest**
Heart Rate at Work	1%	*T, LT, OT*		*T, LT, OT*	
	5%			*O*	
Heart Rate at Rest	1%		*T, L, LT*		*T, O, OT*
	5%		*O, OT*		
GSR at Work	1%	*T*		*T*	
	5%	*O, OT*			
GSR at Rest	1%		*T, O*		*T*
	5%		*OT*		
Heart Sound at Work	1%	Not Available		*T*	
	5%			*LT, OT*	
Heart Sound at Rest	1%		Not Available		*T, LT, OT*
	5%				
Pulse Pressure	1%	*T, L, LT*			
	5%			*T*	
Systolic Pressure	1%	*T, LT*			
	5%			*O*	
Diastolic Pressure	1%	*T*		*O*	
	5%	*O*		*OT*	

T: time period.
L: speed.
O: operator.
* Three subjects.
** Five subjects.

The significant effects were analyzed by the method of orthogonal polynomials. Regression equations were developed for the degree of polynomial which best characterized the effect of time on a given dependent variable. Geometric representations of these functions are presented in Figures 4 through 12. It is obvious that these curves do not represent the true, or expected, relationship between the variables in all cases. The faired-in curves (broken lines) superimposed on certain graphs represent the apparent actual trend of the data. It will be noted in some cases that the computed and actual curves were thought to coincide.

Heart rate was the most operational dependent variable in this study. It was a very sensitive indicator of work at all task levels (Figure 4).

The same functional relationship was found for rest increments except for a lack of sensitivity at mild exer-

cise (Figure 5). This suggests that a relatively small change in the absolute amount of work at mild exercise, for a brief time period, is not critical with respect to rest.

The significant operator time interaction is discouraging; however, it is felt that with larger homogeneous groups this interaction will not exist. This viewpoint is supported in part by the fact that the single replication at strenuous exercise for five subjects was void of such interaction. Existing knowledge indicates that such interaction is anticipated between groups of workers stratified by varying physical condition and work intensity. The heterogeneity among three subjects is illustrated in Figure 6.

HEART SOUND

Heart sound correlated, as one might expect, with heart rate, but it is not considered to be operational. The major difficulty results from artifacts, i.e., sounds other than those related to the heart action, produced by extraneous environmental conditions. Considerable error is introduced by the subject's physical activities of speaking, coughing, and labored breathing. The heart sound data for strenuous work were not usable because of the aforementioned artifacts. The load time interaction effect on heart sound at mild exercise is shown in Figure 7. Heart sound was not found to be a homogeneous predictor among the five subjects.

BLOOD PRESSURE

One of the most encouraging, but least expected, results of the experimentation was the relation between the subjects and pulse pressure. It will be noted in Table 2 that no significant variation was found among subjects for the difference between systolic and diastolic blood pressures, i.e., pulse pressure. This condition held

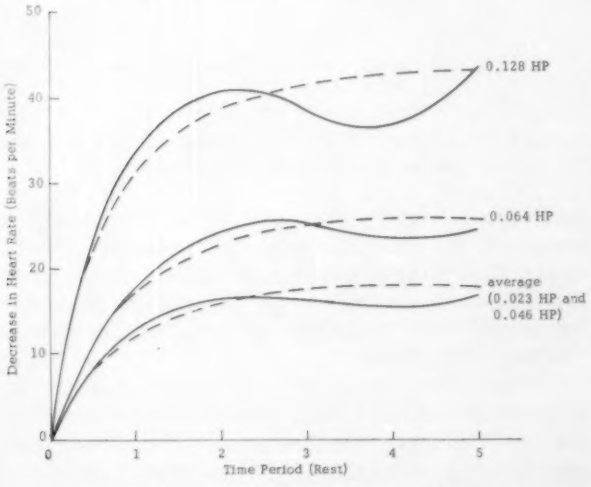


FIGURE 5. Decrease in Heart Rate after Work.

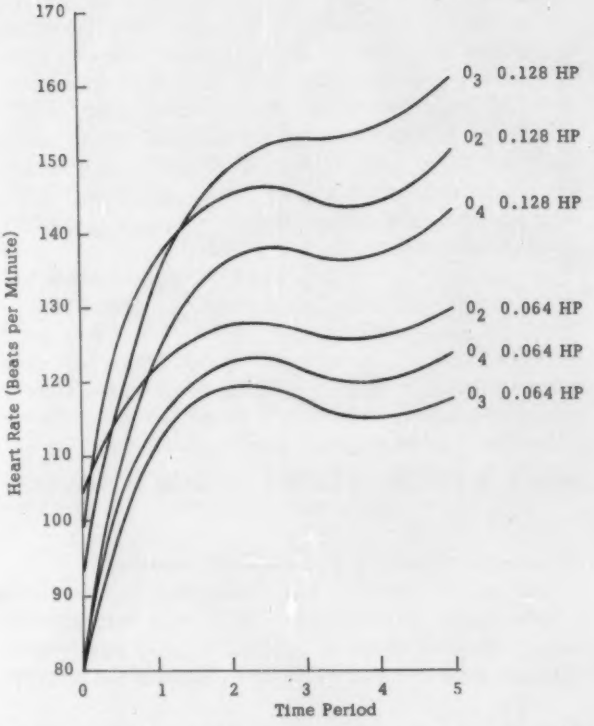


FIGURE 6. Operator Heterogeneity in the Load Time Interaction Effect on Heart Rate.

for both mild and strenuous exercise, hence it cannot be concluded that the lack of significance was due to extremals of energy output. If this lack of significant variation among operators can be validated for larger groups over longer time periods one will be encouraged to consider pulse pressure as a definitive work measurement tool. Another interesting observation regarding pulse pressure was its unilateral sensitivity which discriminated among strenuous task levels as the heart rate approached a maximum (Figure 8).

GALVANIC SKIN RESPONSE

Under the conditions of this experiment the GSR variable increased linearly with work over time at all task levels (Figure 9). This is of interest since the trend of all other dependent variables was quadratic over time.

At this time no explanation can be found for this unique relationship. It is felt that GSR is related to electrochemical changes in the muscles, e.g., hydrolysis of glycogen to lactic acid, and that there is no direct correspondence between the cardiovascular variables and GSR. It is known that the lungs and blood stream have a limited capacity for supplying oxygen to the muscles which sets a limit on steady state energy production. Thus, the physiological factors which compensate for initial, peak, and terminal work cycle energy debits of

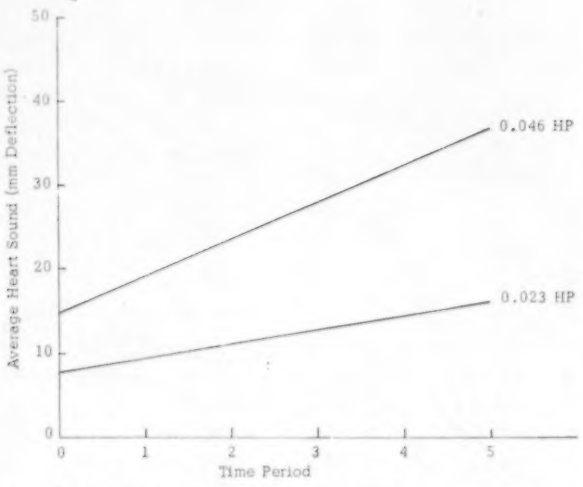


FIGURE 7. The Effect of Load Time Interaction on Heart Sound during Mild Exercise.

the muscles might relate to the GSR measure.

GSR was not sensitive within extremals (i.e., levels of a given task) of work activity. It was homogeneous among operators at the one percent level of significance, but since some operator interaction existed at the five percent level, GSR is not considered as efficient as pulse pressure for a homogeneous measure of physiological cost.

The linear GSR rest functions exhibited an interesting phenomenon, viz., the functions were monotonically increasing through all task cycles (Figure 10). All other dependent variables displayed a rate of recovery during the rest periods. These contrasting results indicate the possibility of multi-stage physiological activities of the human body in accommodating various physiological demands. This suggests the analogy of an automobile battery and generator system where the battery provides

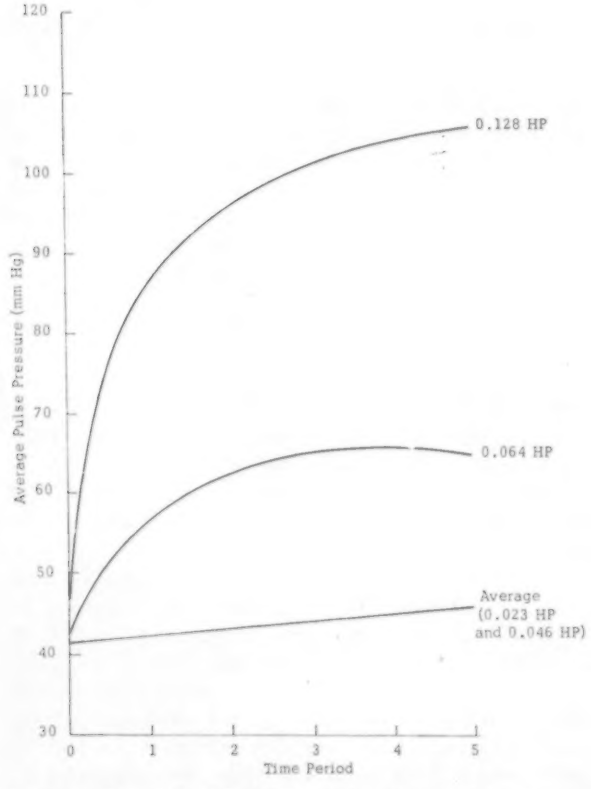


FIGURE 8. The effect of Load Time Interaction on Pulse Pressure during Strenuous Exercise.

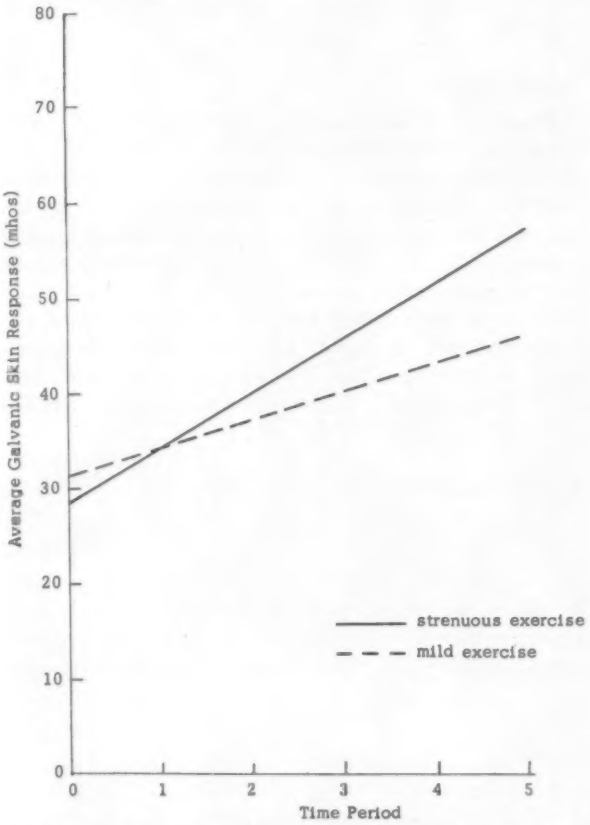


FIGURE 9. The Effect of Time at Work on Galvanic Skin Response during Strenuous and Mild Exercise.

continuity for energy demands over a reasonable time period and the generator augments high energy requirements. Evidently the human generator (the heart) cannot compensate directly for the total energy losses during normal working periods, and one requires rest to "recharge" the system.

All rest curves, except GSR, exhibit a decreasing rate of recovery over work time. This observation validates the intuitive hypothesis that progressively longer rest periods are required throughout the task cycles if recovery to the normal resting level is to be assured.

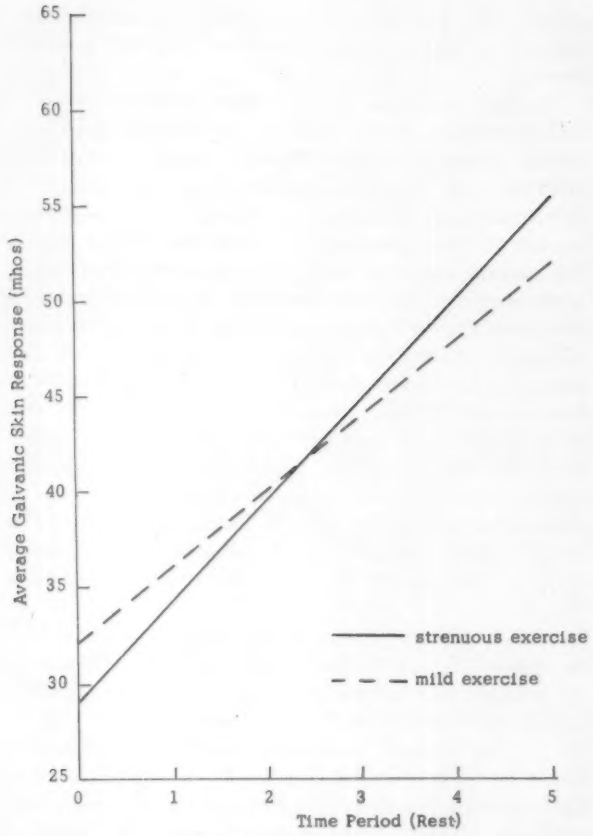


FIGURE 10. Absence of Recovery in Galvanic Skin Response during Rest.

CUMULATIVE PHYSIOLOGICAL COST

Analysis of the combined work and rest increments yields cumulative physiological cost functions (Figure 11). This approach will be beneficial in establishing a measure of a "fair days work" and will also provide an opportunity to determine an optimum solution to the work and rest cycling problem. Physiological cost can be considered as a diminishing efficiency factor whose net output value decreases with work over time. The "cycling problem" requires estimation of diminishing physical efficiency of the human machine (Figure 12), and optimization of the "work to rest ratio." Solution of the cycling problem for various work loads, environmental conditions and physiological concomitants is a challenging goal for Industrial Engineers.

This is only the beginning of an interesting and promising area of research for the Industrial Engineer. Much time and effort are required before we can produce a professionally acceptable methodology. As engineers and scientists, we feel that the technical job can be done, but the political and emotional reactions of both union and management people are unknown quantities which will challenge our ingenuity.

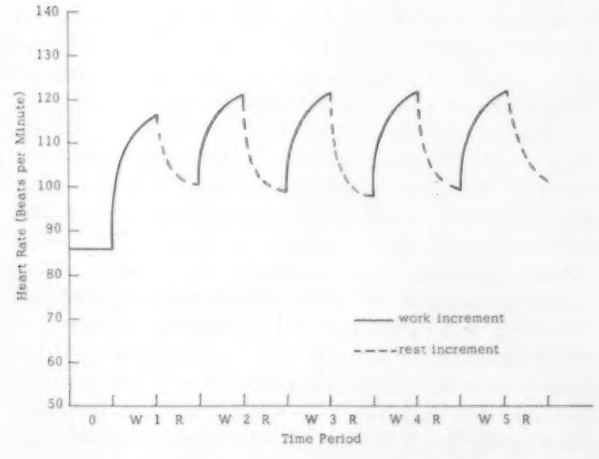


FIGURE 11. The Heart Rate Measure of Cumulative Physiological Cost with Steady State Recovery (0.064 HP).

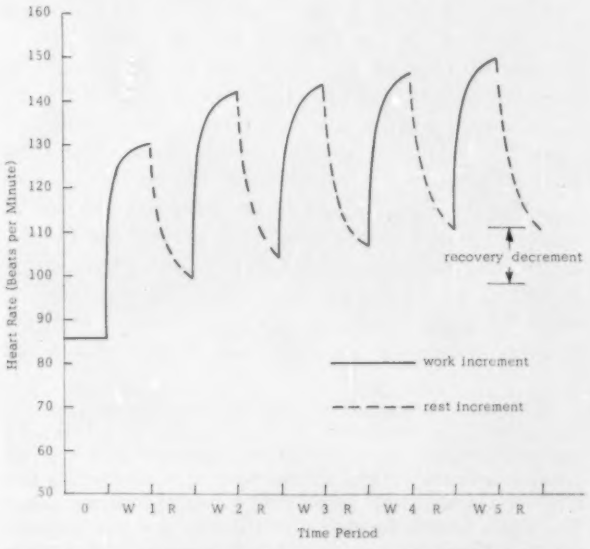


FIGURE 12. The Heart Rate Measure of Cumulative Physiological Cost with Nonsteady State Recovery (0.128 HP).

APPENDIX

REVIEW OF PREVIOUS STUDIES

One of the earliest approaches to physiological measurements is known as the CO_2 method. Pioneers in the field attempted to obtain reliable knowledge about human energy expenditure by measuring the amount of oxygen converted into carbon dioxide (11). The method provided extremely valuable information on the energy efficiency of certain prototype jobs.

The complexity of this early equipment has led some investigators to a negative opinion of physiological measurements. Ingenohl (11, p. 100) states that "physiological measurements can hardly be justified for a mere quick check to determine which one of several jobs ac-

tually requires the greater physical exertion." Recent advances (10) tend to nullify this view however, and lend credence to the oxygen consumption method of physiological measurement.

The Max-Plank Institute employs three methods of measuring work:

1. An exact time study.
2. The respiration gasometer.
3. A continuous pulse rate of the subject during the day.

They have achieved usable results using pulse rate and the respirometer which shows how many calories the subject is burning while working. In addition, they have shown that the pulse rate is directly affected by the environmental temperature. With a nomogram developed by De V. Weir, the results of this gasometer, which is very simple to use and not too bulky, give a fairly good estimate of the physiological cost of work.

Perhaps the most operational of the physiological measurement methods to date is that of Brouha (4). The principle of the method used in Brouha's research was developed in the Harvard Fatigue Laboratory. It consists of counting the pulse rate for 30 seconds at three one-minute intervals during the first three minutes of the recovery period after the termination of work and while the subject is sitting quietly. From these pulse rates a "heart rate recovery curve" can be drawn which indicates the actual values of the pulse and the rate of recovery toward resting level. The heavier the physiological load the higher is the heart rate and the more slowly it returns to its resting level. Thus the physiological stress for a particular job can be determined from the recovery pulse rate measurements. Brouha points out that:

> The onset of fatigue can be predicted from heart rate recovery curves. When no satisfactory recovery can take place between a series of successive operations the first pulse rate after work becomes progressively higher and the heart rate remains at a high level for a progressively longer time during the recovery period. The return toward the resting level is very slow and definitely points to the existence of physiological fatigue in these workers.

Work by Young (19, p. 303) on an experimental basis appears to support that of Brouha. Young investigated the possibility of using the heart rate as an objective measure for rating operator performance on jobs of varying physical intensity. It was concluded that prediction, from heart rate, of task pace energy requirements was possible within the limitations of the experiment. The work of both Young and Brouha appears to lack operational qualities in that the work increment of heart rate is not utilized.

Some investigators contend that fatigue, due to its subjective and complex qualities, cannot be compensated for by purely physiological evaluation. From the few studies attempting to isolate these subjective elements it appears that the difficulty lies in their proper definition. Comparisons of findings by Kerr (12) and Brouha indicate that the onset of subjective and physiological fatigue for large groups in the work situation is closely related.

To date no satisfactory relationship has been established between blood pressure and physiological performance capacity. Wide ranges of pressures have been recorded with subjects adjudged to be of the same physical fitness (2). This may be due in part to the inaccuracy of blood pressure determinations and in part to the medical classification of physical fitness. It is clearly recognized that arterial pressures cannot be measured with precision by sphygmomanometers (20). Direct registration of pressure by calibrated intra-arterial manometers has shown that even during quiet breathing, systolic and diastolic pressures vary from beat to beat by several *mm Hg*, and that these differences are greatly intensified during states of deep breathing. The errors of typical clinical measurement of blood pressure can be summarized by saying that in normal persons a mean error of plus or minus 8 *mm Hg* may be expected in individual readings of systolic and diastolic pressures (20).

Another line of physiological tests uses the electrical resistance of the skin (14). This resistance as measured by ordinary physical methods, shows variation with the activity of the subject. There is now evidence that as the subject becomes more active muscularly, as he becomes involved in an emotion, or as he engages in mental work, the electrical skin resistance is reduced. Consequently, skin resistance is possibly an index of effort and fatigue. It has long been known that the electrical resistance of the skin falls after sudden stimuli. These fluctuations are now generally regarded as a function of sweat gland activity which is controlled by the sympathetic nervous system, a portion of the nervous system which has to do with the control of circulation of the blood.

The level of skin resistance is now often regarded as dependent upon the general level of excitation of the muscles of the body. It is therefore hoped that it will provide an index of the total muscular activity of the body. There is still much fundamental research to be done in determining exactly what it measures, how much influence relatively unimportant factors may have upon the level of resistance, and how accurate it is as a measure of the amount of effort being expended as well as a reflection of the relative changes of effort.

Ross, Dardano, and Hackman (14) found definite trends in conductance (GSR) in groups of subjects participating in a vigilance task. Although no statistically significant relationship was found, it was assumed that high conductance levels are related to high vigilance.

Blank and Finesinger (1) found that GSR increased immediately in a step test. In the present experiments, the exosomatic method of GSR was utilized (9).

It is known that the human body performs best when

it can maintain its temperature at about 98.6°F. Muscular work produces heat and the more work done the more heat which has to be dissipated to maintain normal body temperature.

As the temperature of the work environment approaches, or exceeds, that of the body, the main method by which the body can dissipate heat is by evaporative cooling; i.e., sweating. During sweating, the amount of blood reaching the surface of the body is greatly increased to facilitate loss of heat. As a consequence, for the same amount of work the heart rate becomes progressively faster as the body temperature increases (7) (9). In a study conducted by the du Pont Company (7):

> . . . the reactions of a group of several hundred workers were followed at intervals from March to July. During that period the temperature in the plant shifted from an average of 78°F to 100°F. The average pulse rate after work increased from 92 beats per minute in March to 116 beats per minute in July.

The amount of heat that can be dissipated by evaporation depends not only on the air temperature but also upon the air movement and the humidity. It is generally agreed that below 80°F. the humidity of the air has little effect in producing physiological stress; but as air temperature increases above 80°F., humidity becomes an important factor (7). When evaporative cooling decreases, thus reducing the efficiency of the body for dissipating heat, strenuous work cannot be maintained for a long period of time. Fatigue and exhaustion are reached rapidly with high heart rates, high body temperatures, and resulting very slow recovery processes after work.

In laboratory studies of human energy expenditure the time of day at which task performance occurs has been found highly significant with respect to heart rate following work (16). This agrees closely with studies of subjective fatigue in actual work situations (12). If, in physiological studies, the time of day of task performance, cannot be strictly controlled it is perhaps best, as was done in this investigation, to thoroughly randomize the performance times so that the error introduced by this variable will be evenly distributed.

The age of subjects appears to have no significant bearing on physiological studies if the range of ages of subjects is confined to limits of 17 to 30 (8). Above this range a pace set for younger men is maintained by older men only with an effort which would seem likely in course of time to cause excessive strain.

Brouha (3) points out that it is possible for some individuals to perform hard muscular work with less acceleration in heart rate than is attained by others who fulfill a more minimal task and that it is possible for one man to finish a five minute run with a heart rate no greater than that shown by another who walks for the same length of time. This finding vividly illustrates the marked variations in efficiency in muscular work to be observed among "normal" young men. Brouha's experiments show that while a complete and careful medical examination distinguishes the "healthy" from the "ill," physiological measurements are indispensible for the further and more accurate distribution of normal individuals according to a scale of physiological values based on characteristic functional capacities. These experiments indicate also that physiological differences which already exist during rest among normal individuals are enhanced when the organism is put to work and approaches its maximum capacity.

Various other methods of work measurement include eye blink rate, and electromyography. King and Michels (13) have shown that blink rate could be used to indicate muscular tension in a group of people. However, eye blink rates differ considerably among persons. The blink rate may not be a particularly good index for estimating the degree of tension in any given subject, that is, as a criterion to be used in industry as a measure of individual muscle fatigue.

Wilcott and Beenken (18) have shown an essentially linear relationship for females, and a slightly curvilinear relationship for males, between the force of muscle pull and the integrated electromyographic potential (EMG). A stipulation in this study was that the biceps muscle length must remain constant. Small and Gross (15) tested this variable in a weight lifting task in which the muscle was allowed to change in length. They found that the rate of lifting and the weight lifted were both statistically significant in causing the integrated mean muscle action potential to rise.

No information was found in the literature concerning heart sound as an indicator of work measurement. Also, it was not possible to purchase existing commercial equipment that would sum the heart sounds in a manner that would enable the intensity of the total sound to be measured. From these facts, it appears that this research is the first attempt at using heart sound in an endeavor to find a quantitative indicator of physical exertion.

REFERENCES

(1) Blank, I. H., and Finesinger, J. E., "Electrical Resistance of the Skin," *Archives of Neurology and Psychiatry*, 56, 1946, pp. 544–557.

(2) Brouha, L. A., and Heath, C. W., "Resting Pulse and Blood Pressure Values in Relation to Physical Fitness in Young Men," *New England Journal of Medicine*, April, 1943, pp. 473–477.

(3) Brouha, L. A., and Savage, B. M., "Variability of Physiological Measurements in Normal Young Men at Rest and During Muscular Work," *Review Canadian Biology*, March, 1945, pp. 131–143.

(4) Brouha, L. A., "Fatigue—Measuring and Reducing It," *Advanced Management*, January, 1954, pp. 9-19.

(5) Brouha, L. A., "Physiological Approach to Problems of Work Measurement," *9th Annual Industrial Engineers Institute*, February, 1957, pp. 12–20.

(6) Brouha, L. A., "Physiological Evaluation of Human Effort in Industry," *ASME Paper No. 47–A55*, December, 1957.

(7) Brouha, L. A., "Man's Physiological Reaction to Heat," Unpublished Report, Haskell Laboratory, E. I. du Pont Company, Wilmington, Delaware, 1958.
(8) Brown, Ruth A., "Age and Paced Work," *Occupational Psychology*, 1957.
(9) Deney, L. J., Jr., "An Investigation into Human Heart Rate Recovery as a Measure of Work Rate," Unpublished MS Thesis, Purdue University, May, 1955.
(10) Greene, James H., Morris, W. H. M., and Wiebers, J. E., "A Method for Measuring Physiological Cost of Work," *Journal of Industrial Engineering*, May-June, 1959, pp. 180–184.
(11) Ingenohl, Ingo, "Measuring Physical Effort," *Journal of Industrial Engineering*, March-April 1959, pp. 99–114.
(12) Kerr. W. A., *et al.*, "Changes in Subjective Fatigue and Readiness for Work During the Eight-Hour Shift," *Journal of Applied Psychology*, 1950, 34, pp. 163–166.
(13) King, D. C., and Michels, K. E., "Muscular Tension and the Human Blink Rate," *Journal of Experimental Psychology*, 53, 1957, pp. 113–116.
(14) Ross, Sherman, Dardano, J., and Hackman, R. C., "Conductance Levels During Vigilance Task Performance," *Journal of Applied Psychology*, 43, 1959, pp. 65–69.
(15) Small, A. H., Jr., and Gross, N. B., "Integrated Muscle Action Potentials in a Weight Lifting Task as a Function of Rate and Weight of Lifting," *Journal of Comparative and Physiological Psychology*, 1, 1958, pp. 227–229.
(16) Tarabishi, H. A., "The Relationship between Heart Rate and the Intensity of Work for Selected Tasks," Unpublished MS Thesis, Purdue University, January, 1956.
(17) Viteles, M. S., *Industrial Psychology*, W. W. Norton and Company, New York, 1932, p. 506.
(18) Wilcott, R. C., and Beenken, H. G., "Relation of Integrated Surface Electromyography and Muscle Tension," *Perceptual and Motor Skills*, 7, 1957, pp. 295–298.
(19) Young, H. H., "Relationship between Heart Rate and Intensity of Work for Selected Tasks," *Journal of Industrial Engineering*, November-December, 1956, pp. 300–303.
(20) American Heart Association, *Recommendations for Human Blood Determinations by Sphygmomanometers*, 44 East Twenty-Third Street, New York, p. 3.

Bringing you

needed design facts and technical data on today's engineering materials

In this handbook you will find almost 2,000 pages of answers to both routine and unusual problems that crop up whenever engineering materials are being selected. Technical tables, design information, structural characteristics, and tabular data—a wealth of useful and specific facts—are made quickly available.

Just Out!

ENGINEERING MATERIALS HANDBOOK

Edited by CHARLES L. MANTELL, Consulting Engineer
Newark College of Engineering. *1906 pp., 648 illus., $21.50*

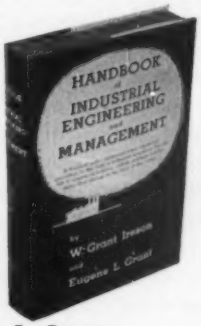
Each of the 43 sections was prepared by one or more specialists. A staff of 150 of these experts cover metals, organic materials, and inorganic materials. Emphasis is placed on the fabricated forms of materials, their physical and mechanical properties, their adaptations, advantages, limitations, competition with each other, protection against deterioration, and increase in their stability to withstand use and abuse.

In line with today's needs, the Handbook covers such items as the uncommon metals which are rapidly reaching commercial importance and production, and the materials of construction of apparatus for control and utilization of atomic forces and fission products.

Order from
American Institute of Industrial Engineers
32 West Fortieth Street
New York 18, New York

HANDBOOK

Industrial Engineering AND Management



Edited by W. G. Ireson and E. L. Grant

A complete reference book for the industrial engineer, manager, businessman and student on the fields of activity commonly considered to be part of industrial engineering. There are 17 sections in all. Each section is complete in itself and is written by an outstanding authority in the field.

Cross-referenced and fully illustrated, there are sections on: structure of business organization, managerial economics, engineering economy, manpower management, motion and time study, factory systems and procedures, industrial climatology, tool engineering, industrial safety, inspection and quality control, and many others.

1208 pages **6" x 9", double col.** ***$16.00***

Order from:
American Institute of Industrial Engineers
32 West Fortieth Street
New York 18, New York

Planning for Research in Management Control Systems—A Suggested Model[1]

by **JAY B. HEYNE**

Manager, Management Control Systems Research, Center for Research in System Development, System Development Corporation

A MATHEMATICAL model has been formulated as a vehicle for conducting research. We believe this model is unique in two ways: in its identification of decision making activity and in its picture of business activity as a queueing network.

First, the model requires explicit identification of managerial decision making in each place where it occurs. The model structure reflects this identification. This concept of management control assumes that decisions are based exclusively on informational inputs. Subsequent investigation using this model may study the decision making process itself.

Second, the model portrays business activity as a network of waiting lines and service centers through which information passes. This information is subject to modification at each service center. This concept of business activity must be compared with the more orthodox representation of business activity which uses an organization chart. Each position shown on the organization chart is viewed in the model as a service center. At each of these centers more than one type of task may be performed. Each of these positions is then called a task center. At each task center a queue of tasks exists. In some cases an output queue of completed tasks may exist.

Two general considerations governed the design of this research vehicle: disaggregation and chance. Disaggregation provides the capacity to study the fundamental characteristics of management activity. Because the proper level of discreteness of these fundamentals is difficult to determine a priori, the model in its pr ent form uses highly disaggregated parameters and variables. An example of this disaggregation occurs in the relationship between the engineering designer and blueprint operator. All communications between these two are explicitly defined and overt exertion of control is required before communication itself can be established. The capability exists in the model of effecting minor variations in management activity for the purpose of studying the effect of such variations. Other reference variables in the model include units produced per production order, individual sales orders, and the number of people at each work station.

The second consideration, chance, is dependent on the first. The model is endowed with the ability to simulate the incidence of a wide spectrum of situations. For instance, normal work loads might not stress the capacity of either the engineering designer or the blueprint operator. A special problem might be created for management with the chance occurrence of a difficult design which might imbalance the work load between them. Breakdown of blueprinting machines might pose another problem for management with regard to subcontracting. The capability of modeling such chance occurrences has been built into the model by the use of stochastic techniques.

The number of simultaneous activities being carried on in the model makes hand computation impossible. The experience of almost all other projects doing research in this area, regardless of the respective level at which activity is aggregated, indicates the need for a computer. When the additional effect of chance occurrence is imposed, the use of automatic computation devices becomes imperative. The computer program for the System Development Corporation model uses, to the fullest capacity, present day programming techniques. Our program requires the use of macro-instructions, compilers, tape storage and associative memory techniques. (A detailed exposition of the problems associated with programming the model for a digital computer needs a separate description of equal length.) An additional comment about the computer program should be made. Namely, the program provides for all activities to be recorded on magnetic tape for the purpose of analyzing any combination of activities offline, or in a manner not conflicting with subsequent experimentation.

Any measure of business activity may be used as an experimentally independent variable. Measures of business activity, generally difficult to define, are not necessary at this time to the execution of preliminary phases of the research effort. This situation derives from our ability to save a great deal of data from each run and to

[1] Based upon work performed at the System Development Corporation, TM-546.

use them later to study relationships not being overtly studied during a given run. An example of this ability might occur when one experimental run suddenly implies the existence of a relationship between inventory level and work force stability. In order to study more data concerning this relationship, previous computer runs might be called from the files to provide such data. Even more important, the ability to record, if not print, all outputs endows each run of the model with a large matrix with which to perform statistically designed sensitivity analyses to determine which should-be the proper measures of system performance.

GENERAL PROGRAM OF EXPERIMENTATION

Although the initial objective of this project is to get a running simulation model based on the concepts described, subsequent research efforts are presently conceived to be as follows:

- *Formulation of hypotheses.* Specific parameter values and decision rules will be selected. System behavior will be observed. Hypotheses will be formulated regarding the effect of parameters and decision rules.
- *Testing of hypotheses.* Experiments will be designed to test these hypotheses.
- *Formulation of objectives.* Objectives will be formulated and the extent to which specific parameters and decision rules will achieve these objectives will be observed.
- *Formulation of criteria.* Criteria will be formulated for selecting decision rules and parameters to achieve specific objectives.
- *Testing of criteria.* Experiments will be designed to test the validity of the criteria.

SEPARATING THE ENVIRONMENT

It has been necessary to differentiate between those activities which are intrinsically related to management activity and those which are related to the business environment. The basis for differentiation is whether management activity can be expected to control the situation. The activities of customers, banks, unions, vendors, competition and the ambient economy are some of the factors which have been categorized as being environmental influences beyond the control of management activity.

STRUCTURING MANAGEMENT ACTIVITY

That part of the mathematical model which is intrinsically related to management activity has been structured in a manner which lends itself to quantitative expression. There are four parts to this structure, which are themselves interrelated. These parts are informational parameters and variables, decision rules, decision areas and company structure. They are defined in the following manner.

INFORMATIONAL PARAMETERS

Informational parameters and variables are those factors which on-line, pragmatic managers understand. They are identified, measured and controlled in the course of management activity which is carried on at all levels except those levels where policy is determined. In the study of business activity it is found that certain variables can be identified which characteristically change with time. These variables describe factors in business activity which may or may not customarily be measured. Waiting time for work-in-process, for instance, is not customarily measured. It is however a significant factor of business activity. If a manager of a business wanted to learn what was happening every minute in all parts of a factory, a relationship of all the variables and parameters might be written as a system of mathematical equations. Such equations could be solved for each successive time period reporting the status of these variables. The solution of these equations is a set of values for the variables. These values describe the state of business activity at a given time. The output of these calculations is then a time trace of the values of each of these variables.

DECISION RULES

Decision rules are defined as the manner in which the latest status of the parameters and variables are treated for the purpose of controlling business activity. The decision rules used in the model define certain transfer functions which are the method of solution used.

DECISION AREAS

Decision areas can be subdivided into the following categories:

1. *Control.* Control decision areas determine which particular decision rule shall be used. Those parts of business activity in which solutions to these equations are called for are defined as control decision areas. These areas become explicitly defined parts of the management structure.
2. *Sensing.* Sensing decision areas which determine the manner in which parameters and variables shall be perceived.
3. *Organization.* Procedural decision areas which determine routing and organization.
4. *Procedural.* Queueing discipline decision areas which determine the order in which activity at a task center shall be performed.
5. *Recording.* Recording decision areas which determine what records shall be kept.

These five types of decision areas each require that respective rules shall be inserted which are associated with each control rule.

THE USE OF STOCHASTIC PROCESSES IN THE MATHEMATICAL MODEL

Although deterministic relationships may be used in the model, generalized use of stochastic, or Monte Carlo, techniques has been made. This use has appeared to be suitable because of two reasons:

ENVIRONMENTAL BEHAVIOR

The behavior of environmental factors lends itself to stochastic modeling. Interactions between business activity and the environment are made more realistic.

DIFFERENTIATING BETWEEN QUALITY OF INFORMATION AND QUALITY OF MANAGEMENT

The necessary differentiation between the quality of information and the quality of management can be made more readily. The quality of management in a business is related to the use which is made of information. If the information is complete, accurate and recent, intelligent use will be reflected in successful business activity. If information is incomplete, inaccurate or late, intelligent use may not be reflected in business activity. If unintelligent use is made of good information, mediocre performance may result. If unintelligent use is made of poor information, even more degraded performance may result.

It is expected that management will take exception to the fact that management activity can be modeled at all. There is a valid basis for this objection since the particular circumstances which apply to the decisions made at a particular time are such that the chances of circumstances being the same in any two cases are slight. Although this is a valid objection, there is a rigorous and quantitative method which can be applied to this problem.

An analogy may help to explain the approach being taken. The objection by management is much the same objection that a dice thrower might have if someone were to attempt to write an equation purporting to describe the expected results for a given throw of the dice. Some factors which might be included in such an equation are: the initial position of dice in the palm, the orientation of the hand, the angle of the wrist at the time of the throw, the surface of the table, the surface of rebound, etc. These factors vary too greatly to allow analytical determination of results for a given throw of the dice. Because of this variation, probabilities in a dice game have been developed on the basis of experience, and it can be shown that these probabilities are calculable for a given throw of the dice.

Similarly, the exposure of a given decision rule to repeated managerial situations will tend to develop a relationship between the rule itself and the results to be expected. While there are more possible combinations in the area of management decision making than in a dice throw, given the use of a tool such as the digital computer the Monte Carlo approach becomes feasible. The number of experimental samples, or computer runs, which can be made during a reasonable period of time lends a measure of statistical validity to such generalized conclusions as may be forthcoming. Hopefully, the present model will be able to simulate six months within ten real minutes. The ability to simulate experience permits a particular decision rule to be exposed to repeated changes over a wide enough range of circumstances. In this manner, the effect of using one rule may be compared with the effect of using another rule. It must be noted that there are limits to the range of circumstances which even Monte Carlo techniques will generate. Those occurrences in business activity which have, say, one chance in a million, might very well never arise in simulation. Resulting observations yield a quantitative statistical measure of the comparative effectiveness of a particular decision rule. Any such comparison must follow validation of the model. Validation may require some reformulation of the Mark I model in order that it comply with a realistic set of parameters and variables. Once validation is accomplished it will become possible to establish criteria related to the choice of alternate rules. The establishment of criteria will of course be subject to techniques of statistical inference.

THE MARK I MODEL

Devolving from the context just described, certain areas have been chosen and organized into a structure of a typical manufacturing company. For the purpose of orientation, certain general characteristics of this company might be cited. The Mark I represents a company which produces a standard product in four models. Specially designed products are available. Activities which have been incorporated are:

- Sales
- Finished Goods Warehousing
- Personnel
- Production Control
- Purchasing
- Manufacturing Administration
- Engineering
- Raw Material Warehousing
- Accounting
- Financial Management
- Manufacturing

Business activities generated in the model are described in detail in this section of the article. Certain control decision rules are also developed. Contemplated extensions of the model are included in the final section of this presentation.

GENERATING ACTIVITY IN THE MODEL

In this section, those activities which are usually associated with business practice are described as they have been generated in the Mark I model. Because sales are in many ways the keystone of business activity, sales generation is used as an initial point of departure. This leads to discussions of how engineering, manufacturing, purchasing and financial management have been modeled. The pervasive effect of personnel department activity is generated as it exists in actuality. All of these activities are then combined to form a system of interactions which can be described as being separate from management control activity, although they interrelate with such control activities repeatedly.

SALES GENERATION

Sales of both standard product and specially designed product are generated in Mark I in the following manner.

In the case of standard product, the total potential demand for standard product is acted upon by six separate transfer functions, each of which has an effect on the total potential demand. Transfer functions are defined as relationships between variables. These are, respectively, the relationship between standard product potential demand and price variation; the relationship between standard product potential demand and quality variation; the relationship between standard product potential demand and lateness of delivery; the relationship between standard product potential demand and advertising; the relationship between standard product potential demand and the number of standard product salesmen; the relationship between standard product potential demand and the cost of standard product sales support. Sales support includes such factors as sales expense accounts and travel. The outputs of these transfer functions are combined to make up the sales volume.

Each of the transfer functions of the external environment has a dual status in the model. Each causes varying effects on business activity. But at the same time, each is subject to perception or sensing by management; and these events may not occur in an accurate manner.

There is also a potential demand for a special product. Transfer functions operating on the potential demand do not result in special product sales; rather they result in a number of requests to submit proposals which may lead to the sale of specially designed product. These requests are generated by transfer functions relating to the potential demand for special product. These transfer functions are relationships between demand and price, quality, lateness of delivery, the advertising budget, the number of special product salesmen, and the cost of special product sales support. Sales support in this case is the same as for standard product.

Another set of transfer functions relates the bids issued in response to requests to a volume of special product orders. These transfer functions are the relationships between proposal acceptance and the size of the order, the delivery date called out on the order, the proposed unit cost and the bid due date. The dollar volume of special product orders is added to the dollar volume of standard product orders, forming the preliminary total sales volume. Orders so included are subject to rejection, cancellation or price variation. Orders, after being filled, are transmitted to the accounting department to be entered as accounts receivable.

The generation of a particular sale in this model is stochastic. Another way of expressing this is to say that the probability of a sale occurring is predetermined, but the occurrence of a particular sale cannot be predicted. This situation is the same as that which applies to a given throw of two dice.

The Relationship between Product Quality and Sales

The manner in which the relationship between potential demand and product quality is generated is as follows. Transfer functions are defined which respond to stochastically varying inputs. These inputs are the percentages of deliveries of each model rejected by the customer. Those activities which affect quality are purchasing, inspection and factory workmanship.

The first place in which control is exerted on quality is at the desk of the purchasing manager. It is here that a control decision area exists. A rule used here chooses among vendors who demonstrate stochastic variation in price, quality, reliability as to due date and cooperativeness. This control decision rule chooses a vendor from among these characteristics.

Depending on the choice made, a stochastically varying percentage of defects is included in deliveries to the factory of each raw material. Of these defects, a stochastically varying number is discovered at the point of incoming inspection. It is in this manner that stochastic variation in raw material quality is generated to affect end product quality.

There is a further degradation in end product quality which results from workmanship in the factory. Workers in each factory department may cause quality to deteriorate. The amount of deterioration depends on the stochastically varying worker effectiveness in each department of the factory. Worker effectiveness in turn depends on training, overtime and factory workload. The percentage of workmanship defects at each factory station is obtained from transfer functions which relate worker effectiveness to the incidence of such defects.

The quality deterioration resulting from workmanship defects is combined with that of defective materials to result in a stochastically varying percentage of final product defects.

The Relationship between Product Price and Sales

The relationship between product price and sales is generated in Mark I. Costs are generated in Mark I in the following manner. A control decision rule chooses a method of pricing in Mark I which calls for price to be determined on a cost basis. One output from the personnel department is payroll costs. The sum of these costs is added to the nonsalary associated expenses, such as interest, advertising and communication expenses for the purpose of computing the total expense. The total cost computation itself experiences a series of time delays which are explicitly generated as described in the next section.

The Relationship between Lateness of Product Delivery and Sales

The stochastically varying percentages of late standard and special product deliveries are respectively generated. The percentage of late deliveries is related to

sales by a transfer function previously described. The actual time delay experienced is generated separately for each product model. This generation requires that information be collected by the sales department to determine how different standard orders, requests to bid on special designs and orders for specially designed product consume time. Other time delays are generated in Mark I in the various departments in the manner described in later subsections.

Delays Contributed by the Sales Department

A stochastically varying number of standard orders, with associated quantities, come in to the sales manager. Standard sales volume is recorded by the sales manager. Sales orders are then transmitted to the sales clerk. Their entry is recorded.

Sales orders are then directed to the sales order processor. The sales order processor uses time to process orders and may hold them for a time, depending on which control decision rules prevail. One operating rule which would effect holding time is that referring to early receipt of sales orders. Such orders may be held until some time more proximate to the delivery date. If the order received by the sales order processor is current as to delivery date, a control decision rule has the sales order processor compare the quantity on that order with the finished goods inventory level, or with reorder point conditions established by a separate control decision rule. From the warehouse manager, the order is routed to the finished goods handler.

Finally, the order is released to the shipper. The shipper may hold up if the finished goods handler had misinformation about incumbent shipping commitments, or if transportation considerations called out by a control decision rule have the shipper wait for the assembly of full carload lots.

If the order quantity exceeds the inventory level, the order is routed to production control where it is combined with previous orders for both specially designed and standard products. Explicit production leveling practices such as economic order quantity and reorder point are based on control decision rules. These rules call out certain parameters which must be sensed as holding cost and cost of lost sales. Explicit determination of these parameters requires the use of sensing decision rules.

Special product orders are treated beginning with requests for bids, as described before. Such requests are generated as a function of the total market potential. These special product orders, as are standard product orders, are sent through the sales department time delay sequence.

Delays Contributed by the Engineering Department

Requests for bids are then sent to the engineering manager. Holding time in this case might be occasioned by a rule which has the engineering manager check his work schedule before undertaking the writing of the proposal. Requests are then sent to the engineering clerk, where record of incoming requests is made.

Requests are then transmitted to the engineering proposal writer. At this task center, the request is written during a variable period of time. The proposal may be held for a time if coordination with production control is required.

Completed proposals are then sent back through the engineering clerk, where record is made, to the engineering manager for sign-off.

Completed proposals are directed to the sales order processor, who records on the sales schedule the fact that a proposal has been submitted. The sales order processor then transmits proposals to the sales clerk. Proposals are then entered into a file which records an associated dollar value. Proposals are then sent to the sales manager for approval. Holding time at this task center may develop if the operative control decision rule requires a credit check of the prospective customer before sign-off. Finally, the proposal is sent to the customer.

As in the actual case, the time delay between submission of a bid and receipt of a special order is not governed by the management control system. This delay is stochastically determined by environmental behavior.

On those occasions where proposals are transformed into special orders, they reenter the company following the time consuming route in the sales department. Special orders are sent to the engineering manager and the engineering clerks. When special product orders are received, the clerk is instructed to transmit them to engineering design. Design then takes place. Holding time between design and blueprinting may be called out by decision rules which govern engineering administration procedures. Completed designs are then sent back through design, the engineering clerk and the engineering manager where approval takes place before being sent to production control in the form of production orders.

Delays Contributed by Manufacturing Administration

At production control both standard product and special product orders wait until they are formed into a production schedule. A time is required to formulate the production schedule. Schedules may be held, depending on the particular control decision rule, for a period of time. One rule might be that schedules are made up for a variable number of days in advance and are updated each day. Conditions for updating may depend on periodic reports such as sales forecasts, factory performance or raw material inventories.

Schedules are forwarded to the plant superintendent where necessary modifications to the schedule are made. The plant superintendent may hold schedules for a time using a control decision rule which might determine the period of holding time. This holding time might corre-

spond to a weekly review of the production schedule.

The schedule is then sent to the plant foreman. The foreman reviews schedules on a periodic basis. The time necessary for foreman review is then used. The fact that foremen review daily determines foreman holding time.

The foreman transmits the schedule periodically to supervisors at each of the factory's sections through which the model must pass. Section supervisors' review of production schedules on a periodic basis is more frequent than that of the foreman. This short period makes supervisory review the most sensitive of any rescheduling which takes place.

Delays Contributed by the Factory

Each model of the product moves through each necessary manufacturing station, taking waiting times, processing and holding times after explicit setup times at each station have been consumed. Processing time takes place when the conditions necessary to processing have been met. These are related to the presence of a work force of nominal size set by a particular control decision rule and to the presence of an amount of material which is related to the amount required to complete the order. Holding time at each station might occur where matching subassemblies must be on hand before further processing can take place and where space limitations prohibit shipments to such stations; or holding time might depend on required approval by inspection.

As models move through the plant, they are at all times subject to the stochastic incidence and varying duration of machinery breakdown. In the case of breakdown, waiting time for maintenance, maintenance processing time and maintenance holding time are experienced. Holding time for maintenance action might occur if a control decision rule were to call for repairs to be approved by supervision prior to restarting.

Reworks may be experienced. Their occurrence is stochastic and they may cause some part of a given production order to be recycled to the queue of a given department, disrupting the tactical production schedule.

The incidence of idle time in manufacturing has three causes: idle time resulting from breakdown; idle time resulting from material shortage; and idle time resulting from insufficient personnel. Material may be found to be in short supply, a determination by the section supervisor. The foreman is then notified. The foreman notifies the plant superintendent. The plant superintendent notifies the warehouse manager. In the case of the warehouse manager, holding time might be the time necessary to determine whether material is in transit to the production floor. If material is found not to be in transit, the warehouse manager may determine whether the material has been inspected. If it has not been inspected, the warehouse manager directs the inspectors to inspect the materials in short supply. If the material has not been inspected because it had not been moved to the raw material inspection area, the warehouse manager directs the raw material handlers to move it.

A file of raw material status is maintained at each place where raw material is stored. This file enables the implementation of a variety of control decision rules. These rules may take the form of LIFO, last-in-first out, FIFO, first-in-first-out or average raw material costing. The warehouse manager may learn that the material cannot be moved to inspection because it has not arrived. The warehouse manager so notifies the plant superintendent. The plant superintendent, upon being notified, tells the purchasing manager to expedite the material ordered.

Delays Contributed by the Purchasing Department

The purchasing manager then activates the purchasing expediters. If it is found that expediting cannot take place because the order itself has not been placed, the purchasing manager directs the buyers to place the necessary order.

The situation just described would be an abnormal sequence in the working of the model. Normal practice has the purchasing manager placing orders far in advance. The number of days in advance is determined by a control decision rule. Given the fact that these conditions have been met, all orders are again brought through the warehouse manager. Orders are then directed to the warehouse finished goods handler. Finally, orders are sent to the shipper and are shipped to the customer. The percentage of late special product deliveries for each special product model is computed as a ratio of the total orders shipped late to the total orders shipped. The number of late standard product deliveries is computed using a similar ratio for each standard product model.

Delays Contributed by Financial Management

Corresponding time delays in accounting and financial management are generated. These do not necessarily occur in sequence with the time delays just described. They might occur in parallel. These are associated with the computation of cash position, accounts receivable and accounts payable.

Inventory accounting procedures take their respective time sequences; computation of the value of raw material inventory requires the necessary use of time to count the total number of units in raw material inventory. This inventory is found in the uninspected receipts and in the raw material inspection department. Computation of the value of work-in-process inventory requires that time be used in order to determine the number of units in process. The evaluation of finished goods inventory requires time. This inventory is found by counting the number of units in the finished goods warehouse.

Total cash needs are developed and compared with cash supplies. A control decision rule applies at this task center which relates the effect on operations of cash

position. The particular rule which applies is developed fully later in this section.

The total cost computation is performed in the accounting department. Profit increments are then added. A specific control decision rule determines how profit increments are to be computed. This method of computation may be dependent on perceived environmental conditions.

More time is consumed where unit prices are computed for specially designed products or standard products. Holding times may obtain at these two places if the control decision rule governing price determination is dependent on sales forecast information which may be delayed in transit. Prices so determined operate on potential demand in a stochastic manner.

Delays Contributed by the Personnel Department

All processing times at each place in the system are dependent on the activity of the personnel department. The reason for this dependence is that the number of people doing a particular job is a controlling factor in how fast the job can be performed. This dependence obtains even if the number of people varies stochastically. This dependence introduces considerations as to how fast the rate at which a task can be performed can be expected to change. The rate at which change itself can be expected is stochastic and partially a function of time delays in the personnel department. The personnel manager correspondingly uses waiting, processing and holding times. A personnel clerk consumes waiting, processing and holding times. Further time delays are experienced at task centers where recruiting and termination takes place. The actual effect of these delays is experienced at the places of task performance which have generated the recruiting requisition or personnel termination notices.

Personnel files are kept not on an individual employee basis, but on a departmental basis. Departmental files are maintained as shown in Appendix A.

The dependence of processing time on the activity of the personnel department corresponds to classical concepts of queueing theory. The personnel department may be assumed to have the capability of adding service channels at those places where service time may be allowed to decrease. Processing times tend to be stochastically varying partially because of the performance of the personnel department itself.

The Relationship between Advertising, Number of Salesmen and the Level of Sales Support and Sales

Other relationships are generated between potential demand in the SDC Mark I model which are dependent on the magnitude of budget allocations for sales salaries, advertising and sales support. Sales salary budget allocations are stochastically modified by the operations taking place in the personnel department. The actual behavior of these environmental factors may or may not correspond to the control sensing rules which are used to anticipate the effect on sales volume of varying the size of these allocations.

ACCOUNTING PRACTICE

Costs are debited periodically against budget allocations in accordance with a control decision rule. Budget allocations are generated using an explicit control decision rule which is explained later in this section. For the total allocation there is a total debit; for the individual credited allocations there are corresponding debits.

SUMMARIZING BUSINESS ACTIVITY IN THE MARK I MODEL

The equations which generate these activities may then be said to define a system of interacting phenomena. Interacting in turn with this activity system are the control system in which the explicit decision rules are located and the environmental system in which the pertinent environmental transfer functions are located. These two systems may be conceived as being constructed of areas into which specific decision rules or transfer functions may be inserted. These two systems interact with each other independently of how they individually interact with the activity system just described. One of the capabilities of Mark I is to show the effect of such system interactions over a simulated long time period. The control system itself may be conceived as a series of servomechanisms which are interlinked in a complex manner. A hierarchy of such rules may be postulated and analytical interrelationships may be established. The response of the combined system is immensely complicated by the stochastic nature of signal transmission from servo to servo.

PROCEDURAL CHANGES

It must be noted at this time that the occurrence of waiting time connotes the existence of a queue. At each incidence of time delay, an explicit queueing discipline decision area exists. Each such area in the Mark I has associated with it an explicit queueing discipline rule. The ability to change each such rule independently of all other rules and independently of the task to be performed endows the Mark I with an ability to determine experimentally the effect of minor procedural changes in business activity.

ORGANIZATIONAL CHANGES

Sequences of time delays are described in this section. These imply a requirement for routing information. Associated with each time delay in Mark I is an explicit organizational decision area. Inserted into each such area are explicit organizational decision rules which govern the routing of information. The existence of such explicit rules in modular form endows the Mark I with the ability to determine experimentally the effect on business activity of organizational changes.

RECORD KEEPING PRACTICES

Recording decision areas are associated with each task. These permit the optional recording of certain variables. The ability to exert options as to what information is to be recorded and to note the effect on overall business activity endows the Mark I with some ability to evaluate the relative effect of various integrated data processing systems.

APPROVALS

Each incidence of time delay has associated with it a possible holding time. These holding times connote the existence of output queues. Entry into such queues is governed by the particular control decision rule which may have been inserted into the control decision area associated, in the Mark I, with each time delay. The control decision rule which makes holding time necessary also includes the condition for release of the information from the output queue. An instance of this control is the holding of a particular task until approval from a separately indicated task has been obtained. Requests for such approval would be generated in the operating task in a manner called for by a control decision rule. These requests would enter the waiting queue at the approving task center. At this task center, approving type tasks may or may not have priority in accordance with the queueing discipline rule which obtains. When action on the approval is taken, the information is released from the output queue of the operating task. Criteria for approval are themselves control decision rules.

In this manner the Mark I has been endowed with ability to exert its own management control at each task to be performed.

MANAGEMENT PERCEPTION

Associated with each control decision rule there may be certain informational variables. Each of these may be ambient in varying states through the Mark I at a given time. Associated with each informational parameter necessary to the exertion of a control decision rule is a sensing decision area. Each such area may have inserted into it a particular rule for perceiving the necessary variable. These rules are explicit. Their existence endows the Mark I with the capability of experimentally determining the value on business activity of relatively precise input information.

CONTROL DECISION RULES

Those activities have been described in the Mark I and those places have been indicated where decision rules are necessary to the operation of the model. Some of the control decision rules which have been included in the preliminary version of the model are rather complex. The insertion of any control decision rule into its applicable area in Mark I first requires that an explicit decision be made to insert any rule at all. In other words, an overt option must be exerted to control.

Budgeting Control Decision Rule

Such a decision rule has been inserted in the Mark I which affects budget allocation. In order to establish a budget allocation, a preliminary rule must be used to determine whether the budget should be allocated. Given the decision to allocate a budget, it is allocated and subdivided in turn with corresponding debits as shown in Appendix B.

The existing control decision rule which permits the budget to be allocated uses the capability of fast, updated debiting which exists in the model. The explicit rule used establishes that the percentage of the total operating allocation which was actually expended during the previous period shall be allocated during the subsequent period, regardless of what the previous allocation was.

Pricing Control Decision Rule

Because of the capability of fast debiting which exists in Mark I, a control decision rule is operable which generates price on the basis of actual cost. Costs of material, direct labor, overhead burden, general and administrative costs, and (in the case of specially designed product) engineering costs are measured and applied. These costs are prorated on a per unit basis. A unit profit increment, based on a separate control decision rule, is added. Determined prices are then related to forecast sales volume. Projected inventory levels are established on the basis of sales forecasts using a transfer function relating inventory level to sales. Price modification is made using another transfer function, the relationship between price and inventory level.

Cash Forecasting Decision Rule

The explicit control decision rule pertaining to projected financial requirements used in Mark I follows: Changes in the respective levels of inventory are governed by explicit control decision rules. These corrections in inventory are dependent on the projected sales volume, vendor lead times or on the production cycle time of each product. When these changes are made they aid in the determination of the projected cash position. The sum of the total allocations requested in accordance with the previously described budgeting control decision rule is added to the corrected inventory levels. This sum is added to accrued taxes payable and the accrued dividends payable.

The total amount available is computed by adding accounts receivable to cash-on-hand and then subtracting accounts payable. If the total needs exceed the total amount available, it is to be expected to become necessary to borrow. Borrowing is contingent on the status of the current asset ratio. If this ratio proves to be satisfactory, borrowing can take place. The short term

interest budget allocation must be increased. If borrowing is not possible, inventory depletions are allowed for. If inventory depletion still admits of a shortage, then budgetary reductions must be made by that percentage, in those allocations which permit, which will cause the total operating allocation to conform with funds available. If the total allocation is less than the total amount available, a decision may be taken to repay short term notes, thereby causing short term interest to decrease.

GENERATING THE EXTERNAL ENVIRONMENT

Separate from both the activity system and the control system is the environmental system. Various transfer functions may be inserted into this third system. The environmental system includes transfer functions describing the customer, the economy, the labor market, vendor characteristics, union behavior, behavior of competition of interest rates, the total potential demand, taxes, subcontracted labor, subcontracted assembly and subcontracted design. This system is separately identified because it is not controllable by any management activity. An interesting point develops. While the behavior of the environmental areas may be expected to exert an effect on business activity, such behavior can only be sensed in a manner ordained by particular sensing decision rules. For the purposes of Mark I it is necessary to make such rules explicit. The activity of sales forecasting may be cited as a case in point. Insofar as management perceives the phenomena to be different from what actually happens, error will be introduced in operation of the management system.

SYSTEM INTERACTION

These three systems, business activity, decision area, and environment, interact in the computation of any one of the variables or parameters. For instance, the processing time for moving the raw material into department 4 in the plant depends on time delays and the personnel level at the raw material handling activity. These factors in turn depend on budget allocation and sales volume. It is possible to cause these interrelationships to be explicitly defined for the purpose of computation so that a time trace of raw material move time can be established over the period of time to be simulated. Such a time trace can be analyzed and correlated against the time of any of the other variables included in the model.

CONCLUSION AND PROJECTION

Having described in rather general terms the operation of the preliminary version of the SDC Mark I model, three facets of the nature of this research become discernible.

It would appear that mensuration techniques seem to clarify themselves as this research progresses. It is now possible to begin to quantify what might be meant by an ultimate "general purpose model." From the point of view of research in management control, it is possible to synthesize a list of control decision areas, sensing decision areas, procedural decision areas, and queueing discipline decision areas into which any number of specific alternatives may be introduced as computer subroutines. Similarly, it is possible to synthesize a list of environmental transfer functions which may be inserted as needed in the environmental system, again as computer subroutines. A measure of the generality of the model then results from the determination of how many cases can be simulated using the latest list of such areas.

A universe of control decision areas may be postulated. By proper selection from this universe, it is believed that a company structure can be uniquely identified. A management control system can therefore be defined as being comprised of those control decisions that are made in the course of business activity.

It is therefore possible to identify, with respect to a given company structure as defined previously, those areas where control decisions are necessary. Given such defined areas, it is possible to identify a set of alternative control rules for making the decision itself. It is necessary that each of the rules in such a set have the necessary variables and parameters available which make the rule operable within the decision area.

It is possible to conjecture at this time that two potential uses of this model may be watched for.

Necessary modification to the current model has been planned for, as it has long been apparent that validation could only take place using real data. It is anticipated that the present program will lend itself to such modification as the opportunity for validation presents itself. Once validated, the model may become a direct tool to be used in quantifying the effect of alternate management policies and rules.

If such quantification can be assumed to be a reasonable expectation of this work, then attention might be directed toward ultimate optimization. An optimized version of this model conceivably could be used as an on-line management control of a business. Study of business activity under such conditions might provide useful input to the larger problems to which behavioral scientists might address themselves.

Allowing for the validity of the previous two conjectures, a third remote possibility might be discerned. If a business system can be simulated, validated and optimized in a manner leading to the ability to aggregate its characteristics into macroscopic form, it might then be possible to study the interactions of two such systems by simulation. If such a two-system study can be validated, possibly a study of a competitive industry can be made.

This possibility leads to further conjecture concerning the characteristics of a given industry which might be so aggregated that the possibility of studying a competitive economy can be envisioned. If it is even remotely

conceivable that such a study can lead to the ability to aggregate the characteristics of an economy, then it becomes possible to conjecture even more remotely about a study of the characteristics of competitive economics. This sequence possibly, just possibly, outlines a path which relates this work to a study of the profound issues of our time.

APPENDIX A

MAINTENANCE OF DEPARTMENTAL FILES

Purchasing Managers
Purchasing Buyers
Purchasing Expediters

Engineering Managers
Engineering Clerks
Engineering Proposal Writers
Engineering Designers
Engineering Blueprinters

Corporate Managers
Corporate Financial Managers
Corporate Controllers
Corporate Accountants
Corporate Pricers

Personnel Managers
Personnel Clerks
Personnel Recruiters
Personnel Terminators

Manufacturing Labor, Section 1
Manufacturing Labor, Section 2
Manufacturing Labor, Section 3
Manufacturing Labor, Section 4
Manufacturing Labor, Section 5
Manufacturing Labor, Section 6
Manufacturing Labor, Section 7
Manufacturing Labor, Section 8
Manufacturing Production Controllers
Manufacturing Plant Superintendents
Manufacturing Maintenance Men
Manufacturing Foremen
Manufacturing Supervisors

Sales Managers
Sales Clerks
Standard Salesmen
Special Salesmen
Sales Order Processors

Warehouse Managers
Warehouse Finished Goods Handlers
Warehouse Shippers
Warehouse Raw Material Handlers
Warehouse Raw Material Inspectors

FACTORS MAINTAINED IN EACH FILE

Budget allocation
Overtime rate
Straight time rate
Number of people desired
Number of people absent
Number of people present
Effectiveness of people in the department
Number of people actually on the payroll
Idle time
Total actual wage and salary charges

APPENDIX B

ACCOUNTS MAINTAINED

All Departments

Personnel Department
Personnel Administration
Personnel Managers
Personnel Clerks
Personnel Recruiters
Personnel Terminators

General Office
Corporate Administration
Corporate Administrative Managers
Corporate Financial Managers
Corporate Controllers
Corporate Inventory Accountants
Corporate Cashiers
Interest
Mortgage Interest
Bond Interest
Long Term Note Interest
Short Term Note Interest
Communications
Taxes
Corporate Cost Accountants
Fringe Benefits

Engineering
Engineering Administration
Engineering Managers
Engineering Clerks
Engineering Proposal Writers
Engineering Designers
Engineering Blueprinters

Manufacturing Administration
Production Controllers
Indirect Overtime
Idle Time
Plant Superintendent
Heat, Light and Power
Insurance
Maintenance Men
Depreciation
Indirect Supplies
Quality Assurance
Plant Foremen

Section Supervisors

Warehouse
Warehouse Managers
Warehouse Finished Goods Handlers
Warehouse Finished Goods Shippers
Warehouse Raw Material Inspectors
Warehouse Finished Goods Space
Warehouse Raw Material Handlers
Warehouse Raw Material Space
Warehouse Incoming Scrap

Purchasing
Purchasing Managers
Purchasing Buyers
Purchasing Raw Material Scrap
Purchasing Expediters

Factory Labor
Factory Labor, Section 1
Factory Labor, Section 2
Factory Labor, Section 3
Factory Labor, Section 4
Factory Labor, Section 5
Factory Labor, Section 6
Factory Labor, Section 7
Factory Labor, Section 8

Using Work Simplification in Research

by **JOHN S. HERRICK**

Chief, Management Engineering Division, Fort Detrick

BEFORE coming into contact with any of its principles or techniques, research workers often show resistance to the term "Work Simplification," both for what it is thought to mean and the frame of mind it creates. In addition, those who attend classes in this subject may fail to gain anything from the time spent in meetings. Results such as these are unnecessary. Of course, a certain amount of resistance to this concept will always be found; however, its acceptance can be increased. Work Simplification, if presented in the proper frame of reference and with suitable adaptation, becomes useful and acceptable to research scientists.

Experience gained at Fort Detrick indicates that the results from applying this technique can be great enough that every effort should be made to tap this potentiality. Also, the need for economy of operations should prompt the use of this technique. Comparisons of recent years will show that the portion of the federal budget devoted to research has been steadily increasing. Similarly, industrial research budgets are either growing or, in some cases, showing allowances for research for the first time. The fact that America is currently spending approximately ten billion dollars for research indicates that improved productivity is imperative.

Since the total consumption of resources and the per unit cost of research has continued to rise, all reasonable means must be used to achieve greater effectiveness and economy. In working toward these two goals, there is every reason to use the proven philosophies of Work Simplification.

There is one basic distinction that must be made: benefits from research is one problem; how to obtain the greatest value from the money spent is another. It is within the latter, the subordinate problem, that Work Simplification can be of greater assistance.

MANAGEMENT CONCEPT

For the most part, the managing of research has left the achievement of effectiveness and efficiency to those who perform and supervise the work. As an ideal, this may not be the best method. However, since it is in common use, more immediate gain may be effected by integrating improvement efforts into the existing concepts.

The concept may have come about through involvement of the managerial principles of control and delegation of authority. Not knowing how to best clarify its principles as the research effort began growing, management may have let delegation override control. Complete revision and retrenchment, while finding an improved managerial method, is probably too late. Therefore, in order to take advantage of time and gain a more immediate improvement in productivity, the existing concept should be used.

With this general guide, one of the tools for increasing the value of the research dollar, Work Simplification, should be designed so that it works with, not against, the management concept. Within this criterion, background, environment, subjects and manner of presentation will be considered.

REQUIRED TRAINING IN GOVERNMENT

Work Simplification is a well established program in the federal agencies. Similar programs have been de-

veloped by the various departments and services, having grown out of a presidential order and a congressional directive which made the program official in 1949. In the Department of the Army, implementation of the authority resulted in a formal type of presentation, not unusual for its time, and in a teacher-student relationship, with a specific employee level as the target. This was indicated in the preface of the Bureau of the Budget Program: "Since the first-line supervisor was the customer, obviously techniques for improving practices cutting across organization lines were not appropriate subject matter." This statement of the Bureau of the Budget provided not only a definition, but often, as in our case, a limitation.

In an objective review of Work Simplification as a whole, Lehrer (1) made a rather complete analysis of the Department of Army program, with this description: "Another criticism of most government work simplification programs is that they concentrate on small problems to the exclusion of broad ones. This is suboptimization, and it is unfortunate that it does develop."

LOCAL LIMITATIONS

We also found that limitations had appeared in a number of places. Just as Lehrer was finding, we noticed that our projects were usually small and limited to one organization. The scope of work was that amount which could be done by one student.

Another limiting factor was the attitude of the work supervisors. Unless they were firm advocates of the Work Simplification Program before their subordinates took this training, many of them looked unfavorably upon employee improvements. This condition was aggravated by the fact that many of the Biological Laboratories' line supervisors were engaged in laboratory work. These people had difficulty in seeing work simplification techniques as being applicable to the work performed in their laboratories.

These and other limitations, when put together, indicated that some kind of corrective action was needed. This conclusion was verified by a survey of the students who had completed the course of instruction. These results indicated that only thirty percent ever thought of the techniques again.

THE NEW LOOK

The steps in the development will be revised after a summary of the new look in Work Simplification. A substantial reorientation was made in the approach. In instruction, the teacher-student relationship was abandoned, the aim being to draw more people into taking part in discussions. In so doing, it was recognized that we would have to forego breadth of coverage and hope for depth of understanding. With this change in method, adoption of the conference format came naturally.

The course leader now became a conference leader, or discussion leader, and devoted his attention to beginning the conference and then keeping it under way. Only if mistaken ideas seemed about to predominate would the conference leader attempt to instruct the group.

A Leader's Manual followed, which was divided into eight parts or conference sessions; these were framed and designed around the conference format. Besides presenting the subject matter, an important purpose of the manual was to restrict the leader from doing too much lecturing.

COURSE MATERIAL

The course material was assembled around the ideas of group participation, and all participants were to be guided toward cooperation and association. The meetings were planned to include, and particularly accent:

1. Resistance to change,
2. Creative thinking, and "brainstorming,"
3. Problem solving procedures,
4. The questioning attitude,
5. Group projects,
6. Selling an idea, and
7. Preparing a report.

These were the human relations and other techniques which would easily lend themselves to conference teaching. From the larger groups, smaller ones would be formed. Each of these would then "brainstorm" the project which it would subsequently study. The conference leader would favor the projects which were more amenable to solution by work simplification techniques. The groups would follow the problem solving procedure and develop solutions.

As the foregoing subjects were being studied and discussed, the techniques of Work Simplification would be woven into the material. These included:

1. Work distribution,
2. Flow process analysis,
3. Motion economy,
4. Work count, and
5. Layout study.

Visual material was used to augment the conference and discussions. Some of the newer, prize-winning movies were shown, and various written handouts were distributed. Among the handouts were attractive and interesting reprints from the current literature. The purpose of these was to provide easier, yet instructive, reading.

The strategy involved was this: As the small groups became interested in the problems which they had selected, it would occur naturally that the fact-gathering techniques of Work Simplification would be most quickly and easily available.

GAINING STATUS

To this conference plan, certain other value-adding components should be arranged from time to time. One of these is to invite a qualified and recognized speaker for

one of the later sessions. In order to share the speaker's talent with more people, others would be invited as an audience but the class members would act as the panel and do the questioning.

Another help, of perhaps higher value, would be the presence of higher levels of management at critical times. Therefore, after the small groups had developed and finished their projects one meeting would be devoted to a verbal synopsis of the written report. People from top management would be notified, well in advance, that the groups had solved a problem, or problems, of particular interest to them. (Perhaps one of these managers had helped select the problem.) Therefore, in the final session they would hear the group presentations.

IMPLICATIONS

By conducting the Work Simplification techniques in this manner, the research workers should have had the following experiences:

1. They selected their own problems.
2. The problems were in the laboratory and research areas of the installation.
3. Work Simplification techniques were found to be suitable.
4. They applied the techniques.
5. Solutions acceptable to top management were found.

INTERIM CHANGES

The question might be asked as to whether anything had been done in the meantime to try to make the official program work more successfully. An earlier effort had been made by the Biological Laboratories to break away from the routine and monotony of the original program. Moreover, it is not intended to imply that there was a total student aloofness to the previous training and training methods. In fact, there was enough response to encourage us to believe that there was a need and a place for Work Simplification in the administration and management of the research program. This convinced us that efforts should be made to integrate this philosophy into the mission of the Laboratories.

Interim changes included the use of more appropriate visual aids: pictorial, graphic and written. In addition, more "give-and-take" was attempted in the instruction. The climate of opinion improved after these modifications were implemented. However, the changes only produced an unmeasurable gain in appreciation of what could be done with the techniques.

Therefore, it was decided to study, and if necessary, completely revise the Work Simplification program.

BACKGROUND FOR IMPROVEMENTS

Before working out specific details we studied the philosophy of Work Simplification. It was remembered that the founder of Work Simplification, Allan H. Mogenson, claimed that it made its greatest gains through the fullest use of the human elements. Although he may have had the more routine factory and office applications in mind, our experience indicated that the same philosophy holds true for the less predictable research activities. Therefore, this was adopted as the central idea: The most important consideration is the achievement of the cooperation of the people who are expected to apply the techniques.

In order to obtain the desired cooperation we also felt that we would have to better understand these people. We therefore looked further. Before cooperation with the program can be achieved and participation in it enjoyed, acceptance of it must be accomplished. In a research installation this acceptance will be more difficult than in less complex organizations. With a program concerning management the difficulty is compounded. Even the title, Work Simplification, seemed to cause rebellion. Reactions such as this are often unpredictable. Out of this complexity will arise the attitude and frame of mind of the people involved. The analysis of this conditioning, or preconditioning, was another area of investigation.

ASSOCIATIONS

Associations of ideas also appeared to work against acceptance by those involved in research. Work Simplification was not unknown but it had long been associated with routine work: office, factory, and storage operations. This association made it difficult for us to link laboratory and work management techniques. Past attempts to establish this link had resulted in some normal reactions as well as some extremes. These extremes included cases of a complete lack of association, as well as attempts to overassociate. Plainly, the attitudes were found to be contradictory. The extremes were of a discouraging frequency and number. However, there were some encouraging optimum linkages.

Research people knew cases, or remembered stories of efficiency experts who were expert in name only, and Work Simplification specialists who did incomplete work because their improvements in one area failed to take into account their effects in other areas. Thus eventually they caused more work than they saved. These blunderings in the field of engineering had left behind some very unfavorable impressions.

Besides the things which they have heard or read about, some scientists and engineers have had personal experiences which influenced their frame of mind when they were introduced to Work Simplification. Thus, the classification of this activity as part of management or engineering may not help to create a favorable attitude. Certain personal experiences with management analysis may have led some research workers to associate these terms with limitations and confinement. Since these were personal experiences, they will be very important and will bring about a need for sensitivity and understanding. If he sees these qualities, the scientist will have less difficulty in accepting the idea that he can use the techniques in the situations as he sees them.

COMMUNICATIONS

Experience has also shown that Work Simplification techniques will not appeal to scientists and engineers if they are not adapted to the language and the way of thinking of these groups. If the material is to be understood, the engineer, or whoever is making the attempt, must break through the language barrier. One of the purposes of this effort is to show that the scientist will gain by becoming familiar with, and using, the techniques. Such a result could be achieved through the use of discussion group techniques.

Communicating through a direct appeal was also considered. It was remembered that research and development demand a high degree of individual ingenuity and creativity. These individual qualities are looked for by research supervisors when reviewing and interviewing potential assistants. Some kind of rapport might be reached if it could be shown that the same qualities are the foci of efforts in teaching, as well as applying, Work Simplification. The manner selected was one which the scientists often use, citation of a published authority, this one being a book by Alex Osborn (2). Citing an authority has two purposes:

1. To provide an opinion which would be generally valued.
2. To show the correlation between the general thought-provoking type of question and the standardized questions of Work Simplification.

Thus, the recognized text is used to help bridge the gaps, or some of them, between present research control measures and work control techniques.

LIMITING THE USE

In spite of all the devices and strategy which may be used the desired results will not be obtained without a certain amount of salesmanship by the engineer. Included in the requirements for this task are the usual needs of being well-versed in the subject and exhibiting a chosen amount of enthusiasm. Of course, care must be exercised that this enthusiasm is used with some restraint.

It must not be implied from this article that Work Simplification techniques are useful in laboratory situations for which they were not intended. For instance, they are not intended as criteria for design of experiments nor for the technical evaluation of laboratory experiments. Rather, they are for the design and adjustment of systems for integrating and coordinating work processes.

Keeping Work Simplification where it belongs, that is, in association with work situations, will prevent the disappointment and disillusionment resulting from misuse. Work Simplification should not be used where another process or technique would serve better.

LOOKING BACK

Although they are obvious in retrospect, it was not until we were gaining experience that all of our facts appeared.

One of the facts that appeared was that all levels of employees do not benefit from the instruction in the same manner. A corollary to this was that employees of different scientific disciplines, even though of the same level, gained benefits in varying degrees.

This led to the conclusion that every course would have characteristics peculiar to that particular group. Hence, the discussion leader would have to be continually alert for changes in moods and receptivity.

In order to prevent stagnation, future work will have to include a continuing analysis of the methods of presenting the material, and of the effectiveness of our communication of ideas to participants in the conference.

TOWARD THE FUTURE

Almost any review of literature and records indicates that our national resources are being increasingly consumed in research and development, and at a faster rate. If the United States is to keep pace with the *demand* for new knowledge, then management, concerned with the *supply*, must focus attention on gaining greater productivity per research man-hour. Work Simplification can play a part by providing the techniques for isolating instances where work can be made simpler or even eliminated.

This is best done by equipping research workers with the knowledge and ability to use Work Simplification tools, and allowing them to make their own improvements. By doing these themselves, they forego the bias which was harbored when these things were done for them. They are thus provided with a "do-it-yourself type of tool.

There is a need for improved productivity in our nation's research work. Work Simplification provides the techniques to obtain improvements. However, before the techniques can be put to work, there must be a change in individual attitudes. Before this can be effected, the need and applicability of these techniques must be proven.

Basically, Work Simplification is a *scientific* method, with particular value in the analysis and resolution of work processes. Since it falls within the area of work, we must accept responsibility for the creative thinking, adaptation, and communication to other people—some of whose main interests lie elsewhere.

REFERENCES

(1) Lehrer, Robert N., *Work Simplification*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1957, p. 288.
(2) Osborn, Alex F., *Applied Imagination*, Charles Scribner's Sons, New York.

Information Content Analysis

by **DONALD K. ROSS**[1]

Donald Ross and Associates, Consulting Engineers

THIS ARTICLE describes an investigation of the use of Information Theory concepts to measure work difficulty or complexity. Information transmission is a fundamental property of the work situation and work difficulty is found to be related to the amount of information required to be processed by the operator. The term "information" is used in a strict mathematical sense and is carefully defined. The determination of the amount of this kind of information required to be processed by an operator for a specified task is called "Information Content Analysis."

INTRODUCTION

As our productive society has become increasingly more complex, emphasis in performance by the worker has shifted from purely physical requirements to performance where mental requirements predominate.

Conventional Industrial Engineering techniques for quantitative analysis of work difficulty or complexity have been concerned largely with the more physical aspects of task performance. These techniques have become less effective with the decrease in physical work content.

Coupled with the decreasing effectiveness of present methods of analysis, one finds a greatly increasing importance to man's actions. Increased productivity has been achieved largely through large expenditure for capital equipment leading to much automated production. Man's role in this machine domain is to provide correction and maintenance and to make decisions; the importance of his action increasing directly with overhead costs and production volume.

The situation is even more acute for tasks of a military nature where operational objectives require capabilities which have long ago exceeded man's capability to perform. His function in these situations is again to monitor and provide decisions. Even in these latter capacities his inability to perform has been a limiting factor in systems design.

Thus, one has the unfortunate circumstance of a decreasing capability to analyze man's function as the need grows stronger.

Difficulty in the performance of work can result from many factors. Physical work may be difficult in its requirements for energy expenditure, manipulative ability or skilled motion and coordination. Work having a degree of mental difficulty may be complex, may require memory or associative capacity, or may demand ability to perceive unexpected signals in noise. In addition, each of these has aspects of rate performance, errors that can be tolerated, and of risks to be taken, not to mention such factors as work environment and feedback of results.

The research reported here provides a basis for quantitative analysis and measurement of most physical and mental aspects of work difficulty or complexity. The method proposed is not generally useful for those tasks in which work difficulty is composed only of *gross* physical effort; however it can profitably be used in work of this nature to supplement existing techniques when at least some degree of control, manipulation or dexterity is required. The technique is most useful in areas where mental requirements predominate.

INFORMATION THEORY AND HUMAN CHANNELS

In contrast with many of the techniques developed for analysis of work difficulty, the Information Theory approach provides a basis for evaluation for man's function not only as an operator, but also as part of the man-machine system. It further permits a comparison between the system with a human operator and the system when completely automated. The model upon which this work is based makes use of the measures of Information tion Theory (15). The model is supplemented with that of decision theory[2] when utility of decisions becomes important (8).

The adaptability of Information Theory to measurement of human activity has been recognized by many psychologists (4) (11), for while Shannon treats the electrical communication channel, psychologists have demonstrated that man's activity can also be considered as a channel, and indeed have shown that for simple tasks there exists a relatively linear relationship between the information required to be processed during an activity and the time to perform it.

Where the communications engineer applies Information Theory to a man-machine-man system, the psychologist applies it to a machine-man-machine system.

Evidence has been obtained by psychologists to show that the measure of the amount of information transmitted by the human channel can be characterized by invariants which are not dependent upon the kind of information processed. It is this finding that permits information measures to become a basis for quantitative measurement of work difficulty.

[1] Also lecturer in Electrical and Industrial Engineering on the staff of Washington University.

[2] The term "decision theory" loosely describes an area of work well exemplified by (8).

If the rate of human effort in transmitting information is expended well beyond levels normally encountered in a work situation, a rate is achieved where further effort leads only to increased errors. This level of activity is surprisingly consistent for most tasks when measured by information techniques and remains so for virtually all of the human population (3). This peak level of activity can be compared with the maximum channel capacity of a communication channel.

When one compares the rate at which information is required to be processed for a given task with the so-called maximum channel capacity, a relative value is obtained which may be compared from one task to the next. Since the maximum rate may be considered constant over wide ranges of tasks, a direct comparison may generally be made between tasks by simply summing the total amount of information required to be processed in each task, and comparing these values.

Information, as used in Information Theory is a statistical concept. Meaning is greatly restricted when compared with the more common usage of the word. The basic measure of Information Theory is the "unit of information" which is defined as *that which permits a choice between two equally likely events.* This unit is called one *bit* of information. This definition of information does not provide, nor even permit, any measure of the value or intrinsic meaning of what is being transmitted, only the probability of occurrence. Meaning is not an inherent property of the transmission of information; it is a function which has measurable value only in relation to the receiver or recipient. Information Theory does not measure what is transmitted, but rather what could have been transmitted.

From the preceding definition of information, the amount of information required to select between N equally likely alternatives may be computed as (15).

$$H = \log_2 N \qquad \text{Eq. 1.}$$

Since the alternatives are equally likely the probability of each is

$$P = 1/N \qquad \text{Eq. 2.}$$

For the more general case, where the probability of occurrence of each alternative is not equal, the average information required to make a selection is given by

$$H = -\sum_i p_i \log_2 p_i \qquad \text{Eq. 3.}$$

where p_i is the probability of the occurrence of the ith alternative.

From Eq. 3., it is evident that an information measure may be derived *whenever there is a set of phenomena, each member of which can be distinguished from the others and where each has a probability of occurrence such that the sum of probabilities is unity.* These requirements are generally quite easily fulfilled.

An elementary situation may involve, for example, a set of input stimuli consisting of four lamps. When a lamp lights, the operator must depress one of four buttons corresponding to the proper lamp. If lamp 1 lights 50% of the time; lamp 2, 30% of the time and lamp 3 and 4 each 10% of the time, the information presented to the operator per stimulus on the average using Eq. 3. is

$$H(x) = -.5 \log_2 \times 5 + .3 \log_2 .3 + .1 \log_2 \times 1 + .1 \log_2 \times 1 = 1.68 \text{ bits per presentation}$$

It is a postulate of Information Theory that in general the output is never completely determined by the input (and vice versa) because noise interferes with the transmission. Noise in this sense may be thought of as any interfering stimulus, reaction, disturbance or error, depending upon one's point of view. As a result of the noise the input and output can never generally be equal in an information sense.

These noise elements give rise to conditional probabilities in transmission of information. For example, the probability of an output y occurring as the result of an input x is first the probability of x occurring times the conditional probability that if x appears y will occur. When converted to information measures, the conditional probabilities are called *errors* in transmission, denoted as $H_x(y)$, when referred to the output; or equivocation, $H_y(x)$, when referred to the input.

Information transmitted from the input of a system to the output is then given as:

$$\begin{aligned} T(x, y) &= H(x) - H_y(x), \\ &= H(y) - H_x(y) \\ &= H(x) + H(y) - H(x, y) \end{aligned} \qquad \text{Eq. 4.}$$

where $H(x,y)$ is the joint probability of x and y. These relationships are illustrated in Figure 1.

When one considers the human operator in a work environment, one deals with a system vastly more complex than even a complicated communication channel. Nevertheless, the measures of Information Theory appear to express meaningful relationships in the case of the human operator. It is necessary however to re-orient one's thinking in considering first, the transmission of information through an electrical channel, and secondly the processing of information including the transmission of information that takes place when the human operator discerns an input and reacts with an output.

It appears that work difficulty is proportional to the information *processed* by the operator. Processed information includes information transmitted to the output by the operator together with extraneous information presented to the operator that was considered for transmission but not transmitted. Processed information will be denoted by the notation $P(x, y)$. Thus,

$$P(x, y) = T(x, y) + H_y(x) = H(x) \qquad \text{Eq. 5.}$$

When the output is also monitored by the operator, it too becomes an input, hence:

$$P(x, y) = H(x) + H(y) \qquad \text{Eq. 6.}$$

If the input and output are quite similar in physical ar-

rangements and mental demands, then observation of either input or output is adequate to some degree. The task requires less information processing and can then be expressed by the relationship:

$$P(x, y) = H(x) + H(y) - K \times T(x, y) \quad \text{Eq. 7.}$$

Where K is some fraction denoting that part of the information transmitted from input to output is redundant. This kind of redundancy has been called "stimulus-response compatibility" by psychologists.

As the rate of processing information increases, the number of errors appearing in the output increases until a rate is finally reached where any additional increase in information processing rate causes an equivalent increase in error rate. This can be expressed by the relationship

$$P(x, y) = H(x) + H(y) - K \times T(x, y) - H_x(y). \quad \text{Eq. 8.}$$

Returning to the previous numerical example, suppose that errors occurred in performing the task, such that the following error frequencies were tabulated for 100 trials:

Lamp Number	Stimulus Frequency of Occurrence	Number of Responses in Error	Number of Correct Responses
1	50%	1	49
2	30%	2	28
3	10%	5	5
4	10%	5	5

This matrix of responses for the task can be evaluated using information measures to give the value for $H(x, y)$, the joint occurrence of stimuli x and output y. An information value for $H_x(y)$, the errors made, can then be calculated from the expression:

$$H_x(y) = H(x, y) - H(x) \quad \text{Eq. 9.}$$

$$\begin{aligned} H(x, y) &= .01 \log_2 .01 + .49 \log_2 .49 + .02 \log_2 .02 \\ &\quad + .28 \log_2 .28 + 4(.05 \log_2 .05) \\ &= .066 + .504 + .113 + .514 + (4 \times .21) \\ &= 2.037 \text{ bits} \\ H_x(y) &= 2.037 - 1.68 \\ &= .357 \text{ bits/presentation, errors.} \end{aligned}$$

In general the computation for $T(x, y)$, $H_x(y)$ and $H_y(x)$ involves solution of a matrix based on observations of the task where the probability of all outputs as a function of all inputs are tabulated. For synthesis procedures values of $H_x(y)$ and $H_y(x)$ can in many cases be rather closely approximated from the situation parameters.

ADVANTAGE OF INFORMATION THEORY TO INDUSTRIAL ENGINEERING

Since information measures are nonmetric they can be computed for any variable with the properties of only a nominal scale, while the more common statistical measures such as variance and correlation are metric and meaningful only for those variables having the properties of at least an interval scale.

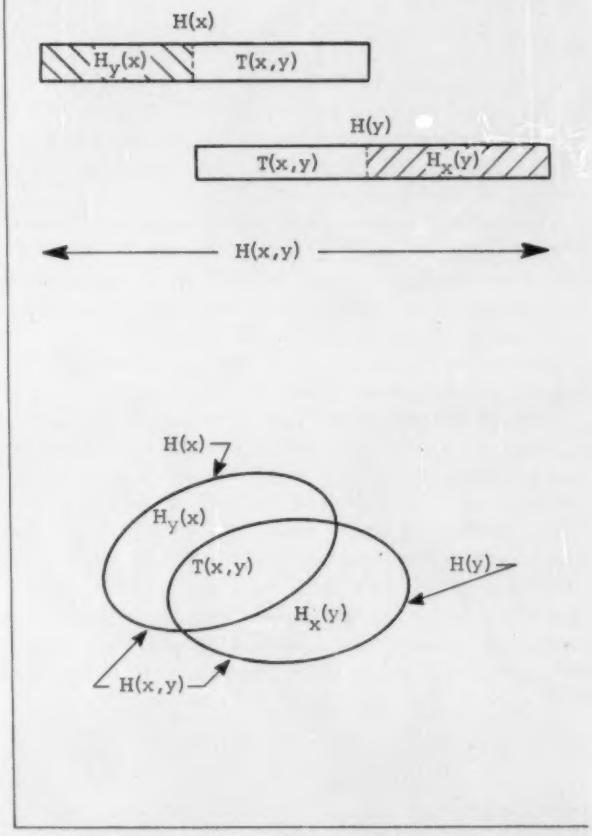


FIGURE 1. Two Diagramatic Methods of Expressing Information Relations between an Input and an Output.

The correspondence of the Information Theory measures to more conventional statistics has been given by McGill (7). He points out that while information, variance and correlation techniques all partition quantities into components reflecting main effects and interactions, information measures may be derived from variance, but the converse is not true.

The resulting simplification of the requirements for the statistics of Information Theory is a great advantage in the area of Industrial Engineering, because it is not required to measure "distance" between categories, but simply be able to identify categories and assign probabilities to their occurrence. Thus for any process requiring selection between alternatives, an information measure of the possible inputs, before selection has taken place, and the possible outputs, after selection has taken place, together with their respective probabilities, provides a measure of the effectiveness of the selection pro-

cess, comparing the selection with that of pure chance. Because such a measure is quite general, it does not reflect the method or basis for selection, thereby permitting broad application.

Accordingly, the results of one process may be compared directly with one of a different nature. For example, two experiments were conducted in which for the first a verbal response was required and in the second a key-pressing response was required to the identical stimuli (1). In both experiments the subjects are required to respond as quickly as possible.

The verbal responses were more accurate but slower, while the key-pressing responses were more rapid but less accurate. It is demonstrated that the information measure shows the equivalence of both sets of responses, even though the responses are quite different.

The maximum rate at which the average well-trained human operator can detect inputs and respond is approximately 25 bits per second (12), these are for tasks such as reading, typing, piano playing and target tracking. For the great majority of tasks where the stimulus response compatibility is not good, such as sorting, selecting, responding to specific stimuli, a limiting rate of approximately 6 bits per second has been observed.

Comparison of these rates with typical tasks reveals that when an operator performs at from ⅓ to ½ of these rates he is considered to be working hard (13), while extremely unusual persons have been found to operate for short periods of time at roughly twice these figures (9).

INFORMATION CONTENT ANALYSIS MODEL

In order to measure the amount of information processed by the operator, twelve factors have been isolated which are believed to comprise most of those having an important bearing on the amount of information processed. There are of course others, such as emotional climate, "set," physical health, and perhaps what Joe Doakes had for breakfast, but most of these relate entirely to the *individual* and are not part of the job specification. For the typical work situation the factors to be presented probably will more than adequately provide all the important aspects of perception—motor activity. In the large majority of cases only a few of them will be significant for a particular task.

These factors are:

1. Total number, or range, of pertinent perceptions and probability of occurrence.
2. Noise and equivocation.
3. Subjective probability.
4. Timing of stimuli.
5. Discrimination between stimuli.
6. Redundancy of stimuli.
7. Short-term memory.
8. Stimuli-response compatibility.
9. Number of sensory modalities required.
10. Psychomotor performance.
11. Rate of performance.
12. Errors permitted.

Analytic formulations have been developed for many of these factors (14). These permit one to measure just how much information an operator is required to process for a given task. Research is continuing, to develop expressions for the remaining factors and to test the adequacy of those already established. Table 1 provides a listing of the factors together with typical analytical formulations.

LEARNING

Several of the factors listed are seen to be related to the learning of a task, and the information associated with them decreases to zero as the task is learned.

This transient information difficulty is composed of four important elements:

1. An incorrect subjective assessment of probabilities.
2. A reduced ability to filter out noise.
3. An inability to associate a stimulus with its proper response.
4. An inefficient means of coding information for storage in the memory.

Evaluation of the information contained in these elements for a given task can provide a measure of the learning difficulty, or alternatively of evaluating the effectiveness of a training program. This evaluation may be made by comparing the operating results of an untrained operator with the task requirements at varying stages of the learning program.

EFFORT IN DECISION-MAKING

Although elements of decision-making take place at many levels throughout the human perception processes and for virtually all psychomotor performance, much of this kind of behavior seems to be intimately connected with the perception-motor process itself.

For the purpose of this research, decision-making has been defined as *that function of human behavior that decides between alternatives, in the presence of uncertainty, when the choices are controlled by utilities external to the human physiological process.* Thus, for example, when the decision difficulty derives from the risks, or values associated with the decision, rather than the difficulty of perception *by itself,* the process is called a decision process.

This distinction is made because it is believed that those human mental processes not included in this definition are measured by the information techniques described thus far. A rather common sense restriction is made that a decision requiring effort must not result from pure chance, or habit.

To evaluate the difficulty in reaching a decision it is proposed to multiply the information content of each complex stimulus times the number of complex stimuli required to reach the decision.

There is some experimental evidence (2) that a general model for human decision-making can be represented by a sequential sampling process. For sequential sampling

INSTITUTE INTERESTS

Individuals, chapter officers, institute officers and others are invited to become primary reporters and send in interesting highlights on local, national and international events. The principal criterion is that the item be current and of general interest. Since publication space represents an investment of your funds, please help us avoid "wordy stories." Material can best be handled if it is typed and double-spaced. Pictures to accompany these notices—or just good pictures with explanatory notes are welcomed. Send the material to Professor Wilson J. Bentley, School of Industrial Engineering and Management, Oklahoma State University, Stillwater, Oklahoma. If you forget this address, send it to the JOURNAL *office in Atlanta, and I will get it.*—EDITOR.

AIIE GENERAL NEWS

CHAPTER DEVELOPMENT PROGRAM
1961 Award Winners

Winners were announced at the Annual Conference and Convention, held in Detroit, Michigan, on May 11-13, 1961. For the first time since the beginning of this program there was a tie for first place. These two chapters completed the year with exactly the same number of points. A "vernier" scale was applied with points assigned as follows: Excellent —4; Good —3; Average —2; Fair —1. This scale was applied to each item in the Program and needless to say it was quite a surprise to find that the two chapters were still tied. The Frank F. Groseclose Award was presented jointly to the Los Angeles Chapter and to the Central Arizona Chapter. Robert H. Edgecumbe, Chapter President, accepted for Los Angeles. Dr. C. B. Gambrell accepted on behalf of F. R. Smith, President of the Central Arizona Chapter. Previous National Champs were Great Salt Lake in 1958, San Diego in 1959, and Milwaukee in 1960. It looks like Region X is setting a fast pace with 4 out of 5 winners.

Listing of other award winning chapters follows:

Third Place—Dallas-Fort Worth
Fourth Place—San Diego
Fifth Place—Miami

Regional Winners were:

Region I—Central Connecticut (3)
Region II—York
Region III—Winston-Salem
Region IV—Miami
Region V—Southern Ontario (3)
Region VI—Cleveland (4)
Region VII—Nashville (3)
Region VIII—Milwaukee (3)
Region IX—Dallas-Fort Worth (4)
Region X—Central Arizona (4) Los Angeles (3)

Chapters qualifying for an "Award of Excellence" were: (In addition to the above)

First Award:

Akron	Mid-Hudson	Sullivan Trail
Chicago	North Alabama	Susquehanna Valley
East Tennessee	Orange County	St. Louis
Erie	Peninsula	Stark County
Great Plains	Philadelphia	Western North Carolina
Indianapolis	Southeastern Virginia	Worcester
Louisville		

Second Consecutive Award:

Birmingham	San Antonio	Twin City
Boston	Southwestern Connecticut	Wichita
Cincinnati		Lehigh Valley
Naugatuck Valley		

Third Consecutive Award:

Chattanooga	Metropolitan New Jersey	Pensacola
Columbus	Niagara Frontier	Savannah
Evansville	Oklahoma City	Tulsa
Long Island		San Diego

Fourth Consecutive Award:

Dayton	Great Salt Lake
Atlanta	Charleston-Huntington

NOTE: (2) Denotes two consecutive years for "Award of Excellence";
(3) Denotes three consecutive years for "Award of Excellence";
(4) Denotes four consecutive years for "Award of Excellence."

STUDENT CHAPTERS

(The Texas Technological College's Student Chapter formed an organization of Industrial Engineering student wives in 1959 and now has 23 members. Following is a report by one of the wives, Barbara Herman, on Past President and Mrs,. Rathe's visit to Lubbock, Texas.)

What a flurry of excitement there was when we heard that Dr. and Mrs. Alex Rathe were coming to visit Lubbock, Texas, on March 8. Knowing the men would have a busy schedule for Dr. Rathe, we, as the wives of the student AIIE members, worked with the Senior AIIE wives to plan a pleasant day for Mrs. Rathe.

Her day began with a tour of the West Texas Museum on the Texas Tech campus, where she caught glimpses of the growth of Lubbock and the surrounding area from cowtrails to rails. The murals depicting early pioneers of this area, painted by the widely-known southwestern artist, Peter Hurd, in the museum rotunda, were of special interest to Mrs. Rathe.

A luncheon in her honor was given in the Hob Nob Room of Lubbock's newest Hemphill-Wells Department Store with the Senior AIIE Wives, the Dean of Engineering's wife, Mrs. John Bradford, and student wives in attendance.

Following the luncheon, Mrs. Rathe was shown some of the various points of interest of the city, such as Prairie Dog Town, MacKenzie Park, cotton oil mills, and other commercial aspects of Lubbock.

After a brief rest, she and Dr. Rathe, the Tech Industrial Engineering faculty, Mr. and Mrs. Ross Hammond, and Dean and Mrs. John Bradford, were entertained at the home of Dr. and Mrs. Richard A. Dudek, preceding their separate dinner arrangements.

After dinner, Dr. and Mrs. Rathe enjoyed a dessert party given by the Student Chapter Wives in the home of Mrs. Dudek. The conversation that followed proved very educational as well as entertaining, and provided much food for thought for next year's programs.

For the third straight year, the Texas Tech Industrial Engineers have won the annual Science and Engineering Show. This third consecutive win enabled them to receive the coveted engineering show trophy. A few of the projects that contributed to their winning the show were: the automated drillpress, closed circuit TV interviews and "pick the whitest towel" explaining statistical significance testing. Barry Buchanan headed the show this year, and needless to say, he did an excellent job.

GEORGIA TECH STUDENT CHAPTER

The Georgia Tech Student Chapter of AIIE and Alpha Pi Mu were co-sponsors for two lectures given by Dr. Robert N. Lehrer, Vice President of Publications and Chairman of the Department of Industrial Engineering, Northwestern University.

Dr. Lehrer's lecture for Thursday evening, April 6, was "PERT —A System's Model for Research and Development Evaluation." His lecture for Friday afternoon, April 7, was "The Contrasting Roles of Scientist, Engineer, and Manager."

Both lectures were well received by the students and staff members of Georgia Tech and industrial leaders of Atlanta and the surrounding area.

With Dr. Lehrer (third from the right) are Georgia Tech Students Willis J. Handel, Leo Anthony Smith, Frederick Henry Binder, Roy William Humphreys and Charles R. Powell.

PERSONALITIES

WILLIAM K. HODSON—TREASURER

WILLIAM K. HODSON

Treasurer, Bill Hodson, is executive vice president of H. B. Maynard and Company, Incorporated, Pittsburgh, Pennsylvania. Bill was chairman of the Financial Planning Committee and is also responsible for liaison between AIIE and the government. Bill also headed up the Task Force on Industrial Engineering Classification in Civil Service. The study by this Task Force was recently completed and a story on the excellent work of this group appeared in the January-February, 1961 issue of the *Journal*.

Bill attended Lehigh University and received a B.S. degree in Industrial Enginering in 1941. He is a member of the honorary engineering fraternity, Pi Tau Sigma. He is also a registered professional engineer in the State of Pennsylvania. Shortly after graduating from Lehigh, Bill was called on active duty as a second lieutenant in the Army Ordnance Corps. He served about a year as a production engineer for the Philadelphia Ordnance District working in a number of plants producing Ordnance material. He was then assigned to the Maintenance Battalion of the 10th Armored Division and spent about eighteen months in Europe. During a part of this time he was responsible for the production of spare parts that were in critically short supply by having them manufactured at French and German plants. Bill advanced to the rank of major before his discharge in 1946.

He then went to work for H. B. Maynard and Company, then known as Methods Engineering Council. Bill started off as a junior staff consultant with this firm and has worked his way up to the position of executive vice president. He is currently in charge of all of their consulting work both domestic and international.

Bill is known to a good many of you since he has presented a number of talks to various Chapters of AIIE. He has also written a number of magazine articles and is an author of McGraw-Hill's *Industrial Engineering Handbook*.

HENRY M. OWADES—VICE PRESIDENT—REGION I

HENRY M. OWADES

Henry M. Owades, recently re-elected Vice President of Region I, is Manager of Research Services, Merck Sharp and Dohme Research Laboratories, Division of Merck and Company, Inc., Rahway, New Jersey. A graduate of New York University (BME 1961; MIE 1954), he is also a member of Tau Beta Pi, Pi Tau Sigma, Alpha Pi Mu, the American Society of Mechanical Engineers, and a registered professional engineer in New York State.

Past professional activities include: charter member and past-president of the Metropolitan New York Chapter of AIIE; organized and conducted the successful AIIE fund raising campaign for the United Engineering Center, for which he was awarded a Distinguished Service Citation by the Institute; member of EJC-ECPD Committee on the Practice of Engineering and the Engineers Joint Council Planning Committee.

In his present position he is applying Industrial Engineering principles to the activities of a research laboratory as a practical demonstration of the institute's objectives toward expanding the horizons of Industrial Engineering into new fields.

JOHN F. SWEERS—VICE PRESIDENT—REGION II

JOHN F. SWEERS

John Sweers, better known as Jack, was born in Cicero, Illinois, during the prohibition era. He graduated from Virginia Polytechnic Institute with a B.S. degree in Industrial Engineering in 1946. Immediately after graduation, he was employed as a Junior Industrial Engineer with the Electronic Blanket Division of Simmons Company in Petersburg, Virginia. In 1948, he moved to Hanover, Pennsylvania, where he became a Senior Industrial Engineer with Doubleday and Company. While with this company, he rose to Plant Industrial Engineer and Production Planning Manager. In 1955 he became a Sales Engineer for Carrier Corporation distributor until 1957 when he was hired as Chief Industrial Engineer for the P. H. Glatfelter Company in Spring Grove, Pennsylvania. He was Data Processing and Production Manager of this company having assumed these duties in June 1960. He has recently accepted a position with the Fitchburg Paper Company, Fitchburg, Massachusetts.

Although, Jack has not been in the Institute for many years, he has been very active during this association. He is a past secretary and president of the York, Pennsylvania Chapter. For the past two years, he has been a member of the Professional Development Committee. This year, he was appointed Regional Chairman of Region II by L. O. Gillette, Region II Vice President.

Jack is married to a VPI coed and has three sons. Besides his work and AIIE affiliation, he is Vice Chairman of the Industrial Engineering Committee of the Technical Association of the Pulp and Paper Industry, he is a member of Rotary, active in scouting, a past member of the Vestry of the Episcopal Church, a speaker at American Management Association sessions, and a Judge of Elections in his district. His hobbies are coin collecting and model railroading.

S. T. NUTTING, JR.—VICE PRESIDENT—REGION III

S. T. NUTTING, JR.

S. T. Nutting, Chief Industrial Engineer for the Camp Division of Union Bag-Camp Paper Corporation in Franklin, Virginia has been elected to the office of National Vice President for Region III, American Institute of Industrial Engineers. In this office, he will be responsible for coordinating the activities of the American Institute of Industrial Engineers chapters in Virginia, West Virginia, North Carolina, South Carolina, and eastern Tennessee. This region contains approximately 500 of the nearly 10,000 members of the American Institute of Industrial Engineers throughout 10 regions in this country and several overseas chapters.

Sid is at present in charge of the Industrial Engineering Department and the Production Planning Department. He has been active in various phases of Industrial Engineering work for Union Bag-Camp for approximately eleven years.

Sid is currently president and past director of the Southeastern Virginia Chapter of the American Institute of Industrial Engineers. He was also a charter member and one of the founders of the American Institute of Industrial Engineers chapter in Savannah, Georgia. In that chapter he served as chairman of various committees and held several offices, including those of president and director. He has served on the Joint Council of Engineering Socities in Savannah, and became its secretary. He is a member of Alpha Pi Mu, the Industrial Engineering honor society.

Besides his engineering activities, he also has been active in civic affairs and is currently serving as the 1961 Campaign Chairman for funds for the Red Cross in Southampton County, Virginia. He is a member of Rotary International, an institutional representative for the Boy Scouts of America, a member of his church vestry, and member of the Technical Association of the Pulp and Paper Industry.

RALPH F. FIX—VICE PRESIDENT—REGION VI

RALPH F. FIX

Ralph joined Firestone in July, 1956, after having been a Director and General Manager of the Clyde Cutlery Company in Clyde, Ohio. He has held various managerial and engineering positions with Crosley Division of AVCO Manufacturing in Evendale, Ohio, and Clyde Porcelain Steel (now Whirlpool Seeger Div.) in Clyde, Ohio.

He studied Industrial Engineering at Montana State College, small business management at Bowling Green State University (Ohio), and completed the Industrial Engineering refresher course at the University of Akron.

I. E. OPPORTUNITIES SERVICE

NOTICE TO MEMBERS

The technicalities involved in modifying our present tax classification require the removal of the I.E. Opportunities Service Bulletin from the *Journal of Industrial Engineering* until further notice.

The AIIE Constitution changes must be approved by the membership and the tax application approved by the Internal Revenue Service before this service may be made available in the *Journal* again.

The I.E. Opportunities Service Bulletin will continue to be published on a monthly schedule for distribution to your chapter only. Inquiries from members based on a review of the bulletin will continue to be handled by the Institute headquarters.

J. F. JERICHO
PRESIDENT

E. P. LANGE
EXECUTIVE SECRETARY

Ralph joined the Toledo Society of Industrial Engineers in 1953. This group was chartered as the Toledo Chapter of the American Institute of Industrial Engineers in 1954. He served the Toledo chapter as a Director.

In 1956 he transferred to Akron and shortly thereafter was appointed Chairman of Membership. In 1957 he was appointed Akron delegate to the National Conference on Industrial Engineering in New York City.

In 1958 Ralph was elected to the presidency of the Akron chapter and has actively served on the Board of Directors since. He is currently serving a two-year term as director of the Akron Council of Engineering and Scientific Societies. He was recently elected secretary of this Council.

Ralph is a member of the Firestone Country Club and Sigma Nu Fraternity. He was formerly an associate member of the Research Institute of America, a member of the Sandusky County (Ohio) Personnel Association, and the District Boy Scout Council in Fremont, Ohio. He was Chairman of the Akron United Fund Drive at Firestone Steel Products in 1957.

JAY GOLDMAN—VICE PRESIDENT—REGION VIII

JAY GOLDMAN

Jay Goldman has been a very active member of AIIE since 1956, having served in many capacities in the St. Louis Chapter, as well as advising the Washington University Student Chapter. He has also done outstanding work as Chairman of the National Research Information Committee. He is a Registered Professional Engineer and a member of NSPE, MSPE, and many other professional, technical and honorary organizations. He has been on the staff of Washington University since 1956 and is an active consultant both in the United States and some foreign countries. He is the holder of several patents and is listed in *Who's Who in American Education, Who's Who in Engineering* and *American Men of Science*.

C. W. WHITSTON—VICE PRESIDENT—REGION X

C. W. WHITSTON

Wit received his preparatory schooling in the east, was graduated from the University of Southern California with a B.E. in Industrial Engineering, and in 1960, received the first professional degree in Industrial Engineering to be awarded at that institution, where he now teaches Industrial Engineering and serves as Coordinator for Relations with Industry, School of Engineering.

All of his life has been a training in management and Industrial Engineering. Starting when he was eleven years old with what he calls the best business primer he knows—he sold newspapers on busy Detroit corners. He soon managed a small group of newsboys and has been in business ever since.

Wit is a past president of the Los Angeles Chapter AIIE, a member of numerous and appropriate technical, honor and social societies and clubs, and has been an officer and director of most.

He has worked in a variety of positions for many large corporations. Countless small businesses have used his talents as director, business consultant, Industrial Engineer or in research. This sums up a productive and versatile amount of activity even to pack into 30 years of experience.

PHIL CARROLL

Phil Carroll was initiated into Tau Beta Pi at University of Michigan on April 18, 1961. Also, Phil was appointed Chairman of the executive committee of the General Engineering Department, one of four groups of ASME Divisions recently formed to help bring about better coverage and collaboration in programming related topics of member interests. Recently, he was made a member of the Advisory Committee for the Industrial Engineering Department of Newark College of Engineering.

INTERNATIONAL ACTIVITIES

Wilson J. Bentley, Head of the School of Industrial Engineering and Management at Oklahoma State University, will spend the three summer months in Europe for the third consecutive year. Wilson is employed by ENI to consult with its management on problems of organization, methods improvement, cost control and reduction and general management problems. ENI is the giant national Italian oil company which has diversified into motels, shipping, manufacturing, petrochemicals and all phases of the oil business. During his absence, Professor Jack Walker of Georgia Tech will edit the Institute Interests.

* * *

TEE H. HIETT

Tee H. Hiett, formerly of the Georgia Tech staff, is now in San Salvador, El Salvador, Central America for a period of two years. At the University of El Salvador, he will be advisor to the director of the newly organized School of Electromechanics—Industrial Engineering. This is a 5½ year curriculum with the last 1½ years devoted to the fundamentals of Industrial Engineering.

INDUSTRIAL ENGINEERING RESEARCH

Northwestern University has announced receipt of a $648,161 grant to provide sharply expanded research facilities in bio-engineering and biochemistry at its Technological Institute.

The grant was made by the National Institutes of Health, U.S. Public Health Service. It will help pay for space and facilities in the $7 million addition, scheduled for completion in the fall of 1962, which Northwestern is building on the Institute.

A wide variety of studies are underway, including the environmental, biochemical and physiological aspects of man's life. Civil engineers are studying environmental control, including atmospheric pollution, water supply and waste treatment, all costly and serious problems in industrialized, urbanized cultures. Electrical engineers and physiologists in Northwestern's medical school jointly are examining the automatic control systems in animals. Biochemists are studying mechanisms of enzymes, clotting of blood, and proteins. Industrial Engineers are examining man as

INSTITUTE OFFICERS 1961-1962

Seated left to right: E. Paul Lange, Executive Secretary; William K. Hodson, Treasurer; William J. Vallette, Executive Vice President; Jack F. Jericho, President; Morley H. Mathewson, Vice President—Professional Services and Planning; Alex W. Rathe, Past President. Standing left to right: Ralph F. Fix, Vice President—Region VI; D. Milton Pitts, Vice President—Region IV; Sidney T. Nutting, Jr., Vice President—Region III; Roger M. Soth, Vice President—Region V; Harry L. Davis, Board Member-at-Large; Jay Goldman, Vice President—Region VIII; Herb Ashcroft, Jr., Board Member-at-Large; Henry M. Owades, Vice President—Region I; C. W. Whitston, Vice President—Region X; Frank J. Johnson, Past President; George H. Gustat, Board Member-at-Large; John F. Sweers, Vice President —Region II; Robert N. Lehrer, Vice President—Publications; Terry S. Leard, Vice President—Region IX; Joseph W. Coffman, Vice President—Region VII.

a part of his own industrial, mechanical society.

The grant gives a further boost to interdisciplinary research at Northwestern. (Last July the school received a $3.4 million grant from the Advanced Research Projects Agency, Department of Defense, to help establish an interdisciplinary center for research in materials).

"It is our belief that much greater progress can be made in solving health problems through joint efforts among the various fields of engineering, plus biology, chemistry, physics, physiology, psychology and systems analysis," explained Dean Harold B. Gotaas of the Technological Institute.

A further idea of the diversity of the attack on the problems of men as living animals can be had by studying the following list of faculty and their health-related research interests:

Civil Engineering: John A. Logan, Harold B. Gotaas and Wesley O. Pipes, Jr., waste treatment; Edwin E. Pyatt and Merrill Gamet, water supply and treatment; and Jimmie E. Quon, atmospheric pollution.

Electrical Engineering: Richard W. Jones and Christina Enroth-Cugell, physiology and bio-electronics; John E. Jacobs, medical electronics and bio-instrumentation.

Industrial Engineering: Gilbert K. Krulee and Robert N. Lehrer, human factors in engineering systems.

Mechanical Engineering: Burgess H. Jennings, air hygiene.

Biochemistry: Myron L. Bender, protein and enzyme chemistry; Irving M. Klotz, protein chemistry; Laszlo Lorand, blood clotting and muscle relaxation; and Robert L. Letsinger, biochemistry.

Biology: Albert W. Wolfson, regulative biology.

* * *

Dr. Raymond Villers has been selected to direct a project which will study the planning and evaluation of research in the United States, sponsored by the Controllers Institute Research Foundation working in association with the Industrial Research Institute. The goal of this project will be to report on Research and Development methods in American industry and propose changes to stimulate improvement.

Dr. Raymond Villers

Dr. Villers will visit some thirty industrial firms where he will work with research personnel as well as those concerned with the solution of financial problems. He will then report on his findings and tell how the two normally divergent points of view—research versus business-oriented executives —may be reconciled.

Traditionally, business-oriented financial executives have tended to be somewhat antagonistic toward research. In the same manner, the research scientists have tended to guard their prerogatives jealously from the prying eyes of financial management. The result has been a loss of motion and liaison between these two integral parts of American industry. Extensive studies have recently pointed up the urgent need to bring these groups in closer harmony for a common benefit.

The Controllers Institute Research Foundation's objective is to foster fundamental research and publish authoritative information on business management with particular emphasis on the principles and practices of controllership and its evolving role in the management of business. The Industrial Research Institute aims at providing the best means for coordinated discussion and study of common problems in modern and improved techniques of research management. By these, the Institute strives to develop and encourage improved practices in the various industries.

SENIOR CHAPTER NEWS

COLUMBIA BASIN CHAPTER

Dr. Merle C. Nutt, Vice President of Region X, presented the charter to the recently organized Columbia Basin Chapter (No. 114) of AIIE, Richland, Washington on April 3, 1961. George Fox, president of the local chapter, is shown receiving the charter from Dr. Nutt. Also shown are Bob Beaver (right), Chapter Vice President, and Chuck Hayner (left), Secretary. In a very interesting program for the event, Dr. Nutt described and showed slides on his experiences in the Orient last summer, where he spent two months consulting in Industrial and Metallurgical Engineering in metals industries.

The Columbia Basin Chapter is initially composed of personnel from the General Electric Company, which operates the huge Hanford plutonium producing plant for the AEC at Richland.

Charter members of the chapter are George Fox, Ray Gilbert, Wally Ruff, Bob Mills Jr., Bruce Benedictson, Dee Ellingson, Al Morganthaler, Bill Kaufer, Bob Harvey, Bill Watson, Bob Beaver, Russ Estes, Les Samford, Duane Snyder, Don Darsow, Bob Wheaton, Jack Chatten, and Chuck Hayner.

COLUMBUS CHAPTER

The Columbus Chapter of the American Institute of Industrial Engineers installed their officers for the 1961-62 year at the May meeting held at the Nationwide Inn. Left to right are: Treasurer, Carl Busch, Section Chief Industrial Engineer, Western Electric Company; Secretary, John Reichenbach, Product Engineer, Western Electric Company; President, Ken Landis, Plant Manager, Harrop Ceramic Service Company; and Vice President, Charles Thomas, Manager of Manufacturing Enginering, Jeffrey Manufacturing Company.

DALLAS—FORT WORTH CHAPTER

"The Anatomy of Control" was capably discussed by Jerome Barnum, President of Jerome Barnum and Associates, at this Chapter's Sixth Annual Management Forum held at the Marriott Hotel in Dallas on March 30, 1961. Among the 100 people attending this all-day conference were managers and engineers from more than a dozen major cities in Region IX. Control was stressed as one of the three basic functions of management, although good control cannot offset poor planning and coordination. The minimum controls necessary in a well organized company were covered in detail. The afternoon sessions were devoted to the problems involved in working with and through people to get good control results, since actual results are obtained from what people do, and not from the reports they read.

FORT WAYNE CHAPTER

At its May meeting, the Fort Wayne chapter elected a new slate of officers for the 1961-1962 year. The officers are as follows: President, David Blanford, General Electric Company; Vice-President, Byron Wyse, I.T.T. Federal; Treasurer, Charles R. Bryson, I.T.T. Federal; Corresponding Secretary, Warren A. Goodlad, Joslyn Stainless Steel; Recording Secretary, Robert Glass, Model Engineering.

During the coming year, the chapter intends to develop seminars and special study groups for chapter members in addition to the regular meeting schedules. These groups will cover current interests of the membership in Industrial Engineering activities.

The Chapter also plans a one day comprehensive conference on an area of Industrial Engineering in the early Spring of 1962.

LOUISVILLE CHAPTER

The Louisville Chapter has organized a review class for those interested in taking the written examination for license in Industrial Engineering. The group will meet regularly from September, 1961, through May, 1962, to review old examinations and discuss possible problems.

MADISON CHAPTER

On May 23, 1961, a meeting of fifty members and guests attended a charter presentation meting at the Hoffman House in Madison, Wisconsin. Dr. Lillian Gilbreth represented the National Organization of the American Institute of Industrial Engineers in presenting the charter to the Madison Chapter, which is Chapter 115 of the AIIE. In presenting the charter, Mrs. Gilbreth outlined the privileges and responsibilities that go with membership in the National Organization of the AIIE. In addition, Mrs. Gilbreth spoke briefly of the progress which is taking place in obtaining cooperation and interchange of ideas in the management field at an international level.

Some of the guests who shared in the occasion were R. A. Dimberg, former Vice-President of Region VIII, whose efforts led to the organization of this chapter, J. T. Brown, President of the Milwaukee Chapter, and Mel McGowan, President of a new chapter being organized in the northeastern section of Wisconsin. Other guests included Mrs. Ben S. Graham, and Ben Graham, Jr., who were here in Madison presenting a program on paper work simplification.

NAUGATUCK VALLEY CHAPTER

The Naugatuck Valley Chapter (No. 97) headquartered in Waterbury, Connecticut, sponsored a labor-management conference entitled "Operation Survival." It was a one-day seminar featuring labor-management views on foreign competition and methods improvement. The Seminar. The seminar, held in Waterbury, had as participating speakers two prominent area representa-

Taking a "break" at the Naugatuck Valley Chapter's seminar, "Operation Survival," are: left to right, Sherman C. Brown, Seminar Chairman; Ralph H. Bavier, Chapter President; John J. Driscoll, Executive Secretary, Connecticut State AFL-CIO Labor Council; Arthur S. Nippes, Vice-President, Waterbury Farrel Foundry and Machine Co., Division of Textron, Inc.; and Henry M. Owades, Vice-President, Region I.

tives from "each side of the fence" discuss these important national issues and their effect on the local scene.

Conducted by Henry M. Owades, Vice President, Region I, "Operation Survival" was attended by nearly 100 representatives of labor and management, including a few from the neighboring state of Massachusetts.

Philip Arnow, Assistant Commissioner, Bureau of Labor Statistics, U.S. Department of Labor, seminar keynote speaker who provided the government outlook on problems of foreign competition stated that "this seminar is one of the first meetings of its kind held in the United States and its might well turn out to be precedent-setting in its atmosphere of conducting such discussions outside the heat of negotiations."

Honorable John S. Monagan, Congressman from the Fifth District, State of Connecticut, in a letter to Chapter President Ralph H. Bavier said, "I was very pleased to hear of the seminar 'Operation Survival' which has been organized by the Naugatuck Valley Chapter, American Institute of Industrial Engineers. I do want to congratulate you and the members of your organization on arranging this seminar on the vital question of foreign competition. To solve this problem will take the highest degree of statesmanship. I am sure that many worthwhile suggestions will emerge."

The general reaction of the audience who heard John J. Driscoll, Executive Secretary of the Connecticut State AFL-CIO Labor Council and Harry B. Purcell, Vice-President, Torrington Company, Torrington, Connecticut discuss foreign competition, with Arthur S. Nippes, Vice-President, The Waterbury Farrel Foundry and Machine Company, Division of Textron, Inc. and Keith Prouty, Research Director, Connecticut State Labor Council discussing cost reduction through methods improvement, was that the seminar was constructive.

SOUTHERN PIEDMONT CHAPTER

The Southern Piedmont Chapter (No. 113) in North Carolina, has experienced rapid growth since it was chartered in January. The Chapter, which meets in Charlotte, North Carolina, had 31 official members as of May 1. The Chapter officially received its charter on January 28 from Dr. Alex W. Rathe.

CALENDAR

1961

July 23-August 4: The Tenth Annual Columbia Utility Management Workshop, Columbia University, New York 27, New York.

July 31-August 31: Quality Control by Statistical Methods, University of California, Los Angeles, California.

July 31-August 31: Industrial Statistical Methods, University of California, Los Angeles, California.

July 31-August 31: Statistical Design and Analysis of Industrial Experiments, University of California, Los Angeles, California.

July 31-August 31: Engineering and Management Responsibility, University of California, Los Angeles, California.

August 21-31: Quality Control by Statistical Methods, University of Michigan, Ann Arbor, Michigan.

September 5-15: Statistical Methods and Advanced Quality Control, Purdue University, Lafayette, Indiana.

September 12-15: Seminar for Manufacturing Engineers, Pennsylvania State University, University Park, Pennsylvania.

September 15-16: Region X Conference, Olympic Hotel, Seattle, Washington; Seattle Host Chapter; Chairman, Richard K. Fox, State of Washington—Department of Commerce and Economic Development, Industrial Division, Olympia, Washington.

September 17-22: Work Measurement Conference, Pennsylvania State University, University Park, Pennsylvania.

September 21-22: Region III Conference, Charleston, West Virginia; Charleston-Huntington Host Chapter; Chairman, P. C. Emmons, 1239 Kanawha Terrace, Huntington, West Virginia.

October 5-6: Region VIII Conference, Marott Hotel, Indianapolis, Indiana; Indianapolis and Central Indiana Host Chapters; Chairman, Robert Batchelor.

October 8-11: International Systems Meeting of the Systems and Procedures Association, P. O. Box 6175, Cleveland, Ohio.

October 12-13: Region I and II Conference, Pocono Manor Inn, Pennsylvania; Lehigh Valley and Binghamton Host Chapters; Chairman, F. Charles Eichel, Industrial Engineering Department, Riegel Paper Corporation, Milford Mill, Milford, New Jersey.

October 13-14: Region IX Conference, San Antonio, Texas; San Antonio Host Chapter; Col. Cassius McCredie, Box 44, CMU, Lackland Air Force Base, Texas.

November 8-10: First Joint National Meeting of the Operations Research Society of America and The Institute of Management Sciences, Jack Tar Hotel, San Francisco, California.

November 17-18: Region IV Conference, DeSoto Hotel, Savannah, Georgia; Savannah Host Chapter; I. H. Carr, 29 Flinn Drive, Savannah Georgia.

1962

May 17, 18, 19: Thirteenth National Conference and Convention, Ambassador Hotel, Atlantic City, New Jersey; Metropolitan New Jersey Host Chapter; Chairman, Elio Rotolo, 47 Merker Drive, Edison (Fords P. O.), New Jersey.

September 27, 28, 29: Region X Conference, Hotel Del Coronado, San Diego, California; San Diego Host Chapter; Chairman, L. R. Becht, 701 Balboa Avenue, Coronado, California.

1963

May 9, 10, 11: Fourteenth National Conference and Convention, Denver, Colorado; Rocky Mountain Host Chapter; Chairman, E. D. Williams, Industrial Engineering Department, United Air Lines, Stapleton Field, Denver 7, Colorado.

1964

May 13, 14, 15, 16: Fifteenth National Conference and Convention, Sheraton Hotel, Philadelphia, Pennsylvania; Philadelphia Host Chapter; Richard W. Walton, 804 Old Lincoln Highway, Langhorne, Pennsylvania.

TABLE 1

Tabulation of Informative Factors

Factor	Description	Typical Analytic Formulation	Remarks
H_a	Total number or range and probability of occurrence	$-\sum_{i=1}^{n} p_i \log_2 p_i$ bits	Other expressions available for known populations
H_b	Noise and Equivocation	$-\sum p_i(n) \log_2 p_i(n)$ bits	
H_c	Subjective probability	$-\sum p_i \log_2(w_i/p_i)$ bits	Diminishes with learning
H_d	Timing of stimuli	$\log K_d\sqrt{2\pi e\sigma_T{}^2}$ bits	
H_e	Discrimination between stimuli	$-\sum_{ij} p_{ij} \log_2 (x_i - x_j)/x_i$ bits	x_i always chosen greater than x_j
H_f	Redundancy of stimuli	$T(x, y)$ bits	Special interpretation of $T(x, y)$
H_g	Short-term memory	$K_g \log_2\left(\frac{N_c \times N_d}{1 - \frac{H'(x)}{C}}\right)$	
H_h	Stimulus-Response Compatibility	$K \times T(x, y)$	
H_i	Number of sensory modalities required	Not important in this application	
H_j	Psychomotor Performance	$-\log_2(W_s/L)$	
H_k	Rate of performance	Obtained by dividing all applicable elements by the cycle time	
H_l	Errors permitted	$-H_x(y) = (p \log_2 p + q \log_2 q)$	

EXPLANATION OF SYMBOLS IN TABLE 1*

p_i—Probability of occurrence of ith stimulus.
$p_i(n)$—Probability of occurrence of ith noise stimulus.
w_i—Subjective probability of occurrence of ith stimulus.
K—Constant of proportionality.
e—Base of naperian logarithms.
σ_T—Standard deviation.
P_{ij}—Joint probability of occurrence of stimuli i and j.
X_i—Physical measure of stimulus i, made in subjectively equivalent units.
$T(x, y)$—Information common to both x and y.
N_c—Number of "chunks" retained in memory
N_d—Number of "moments" memory is required.
$H'(x)$—Rate of information transmission from source.
C—Maximum channel capacity.
W_s—Target dimension in direction of motion.
L—Maximum extension to which movement is possible in direction of motion.
q—$1-p$.

* More complete explanation is to be found in (14).

the decision space can be divided into three regions: accept an alternative, reject an alternative or continue sampling (Figure 2). In this procedure the number of observations required to accept or reject an alternative are not necessarily the same.

If it is assumed that rational human behavior is motivated by the desire to assign values to consequences and probabilities to events, and then to select the alternative with the greatest expected value, analytic expressions may be derived which separate the three regions of the sampling space. A separate decision space or sequential sampling plan is constructed for each of the possible alternatives.

Under the foregoing conditions the analytic expression defining the boundaries of the three areas must then be functions of at least the following variables.

1. Utility of a correct acceptance, U_a.
2. Utility of a correct rejection, U_r.
3. Utility of accepting when should have rejected, U_β.
4. Utility of rejecting when should have accepted, U_α.
5. Cost of taking each sample, K.
6. Break-even utility of accepting an alternative, B_a.
7. Break-even utility of rejecting an alternative, B_r.
8. Confidence level of decision after taking each sample, C.
9. Difficulty of distinguishing between two or more alternatives, J.
10. Number of stimuli taken, N_s.
11. Number of stimuli indicating the alternative under question, N_i.

A general analytic expression relating these factors subject to the foregoing restraints is then found to be:

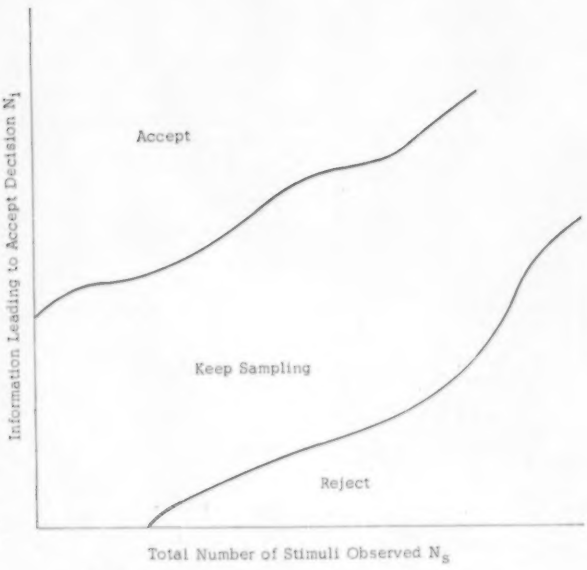


FIGURE 2. Sequential Sampling Decision Space.

$$U_a \times J \times C \frac{N_i}{N_s} + U_\beta \left(1 - J \times C \times \frac{N_i}{N_s}\right) - N_s \times K \geq B_a \quad \text{Eq. 10.}$$

$$U_r \left(1 - J \times C \times \frac{N_i}{N_s}\right) + U_a \times J \times C \times \frac{N_i}{N_s} - N_s \times K \geq B_r \quad \text{Eq. 11.}$$

Qualitatively the first expression states that for an alternative to be accepted: the utility of its acceptance times the probability that this is the correct alternative; less the utility of the cost of accepting when rejecting was correct, times its probability; less the cost of sampling, must be equal or greater than the break-even utility for acceptance.

The second expression is similar and applies to the level at which the alternative is rejected.

These expressions provide the means of computing the two curves of Figure 2 which divide the decision space into the three zones of accept, reject and keep sampling. Note that decision-making can logically stop with no decision to accept or reject being made if the sampling cost gets large enough to preclude the left hand side of the expression from ever exceeding the right hand side.

The most likely value of N_s required to select an alternative is the average sample number (ASN) for this sampling plan.

There being no analytic solution for the average sample number of these expressions, it is proposed that a model of the population of all possible stimuli be sampled by a computer, subject to the constraints of Eq. 10. and Eq. 11. The average of many trials to determine the number of stimuli required to reach a decision may be considered to be the average sample number.

The total task difficulty including that of decision-making is then:

$$H = D \sum_{n=1}^{ASN} H_i \approx D \times (ASN)\overline{H} \quad \text{Eq. 12.}$$

where D is the effective number of alternatives, $\overline{H}$ is the average information content in each stimulus.

RESULTS OF SOME INFORMATION CONTENT ANALYSIS APPLICATIONS

To determine the suitability of the Information Content Analysis model to describe human work difficulty or complexity, several comparisons have been made between difficulty as measured by information content and by more conventional measures such as performance time, or the number of errors made, etc. One test of the model involved computing the information required to be processed by an operator for a specified task and measuring the time required for performance.

The task is then varied by changing the amount of information to be processed. The time for performance under these changed conditions is again noted. In particular, the results of an experiment by Crossman (5) have been expressed in information measures, with the results shown in Figure 3.

In this experiment the subject was required to sort cards into piles in accordance with the length of lines

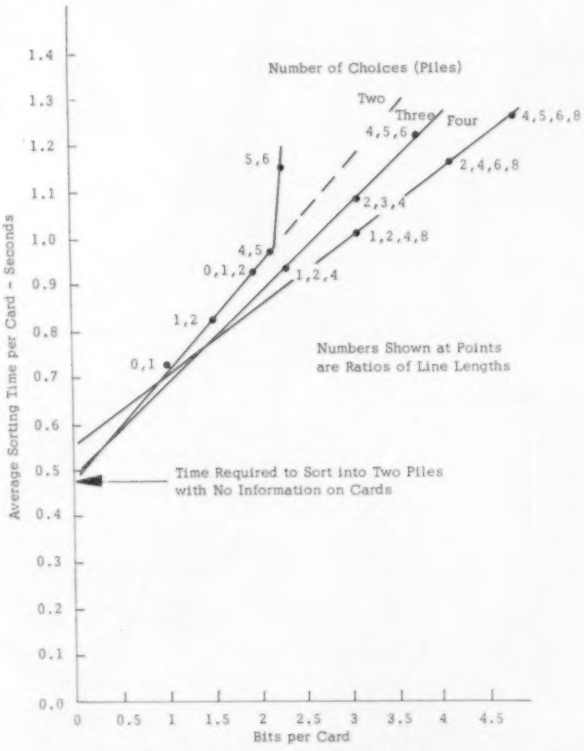


FIGURE 3. Time to Sort Cards into Piles as the Sum of Discrimination Difficulty and Number of Choices.

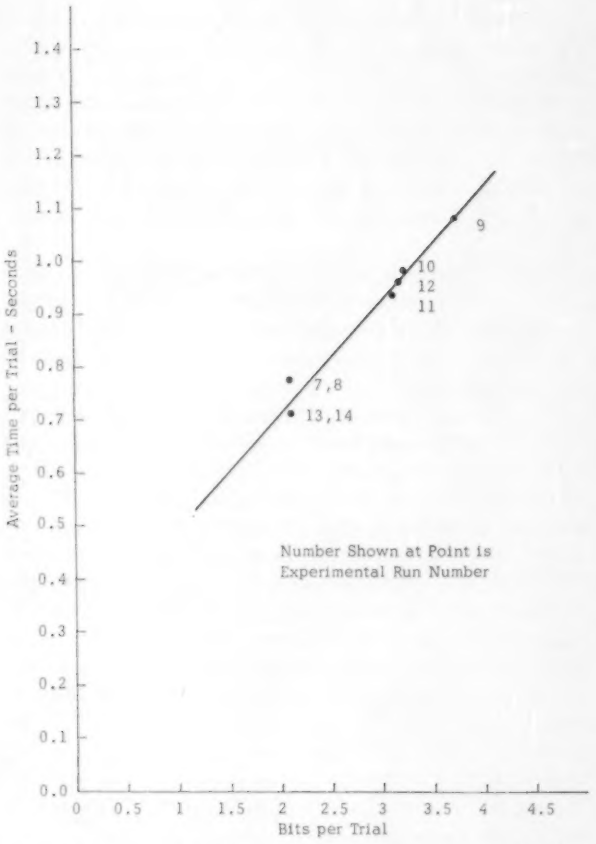


FIGURE 4. Time to React as the Sum of Equivocation, Subjective Probability and Number of Choices.

appearing on the cards. The three curves are representative of three groups of experiments in which the number of piles to be sorted varied. The time to sort each card is plotted as a function of the amount of information contained on the cards on the average. It is to be noted that by extending the curve back to the ordinate (the condition with no information on any card), the resulting time is the same as that actually measured to be the time required for sorting cards into piles indiscriminately!

The three curves could be made to overlap by including in the calculation for each, the proper amount of information in the stimulus-response factor. However, no analytic formulation of this factor has as yet been developed. Further experiments such as the one described are planned to help evaluate the optimum coding aspects of stimulus-response compatibility. In this experiment the information factors considered were the number of choices and the difficulty of distinguishing between stimuli (line lengths).

A second comparison has been made with an experiment in which the information factors evaluated were the number of choices, improper subjective probability and equivocation. These results are given in Figure 4 where, again, performance time is shown to be linearly related to the sum of the information factors. In this experiment, from Leonard (6), key-pressing responses were required for flashing lights. In the experiment some false signals were given, leading to equivocation and to stimulus-occurrence probabilities different than those in the training period.

A third test of the model involved the comparison between the difficulty of two tasks by computing the number of errors performed in each. Data from an experiment by Poulton (10) were employed in this comparison.

When the number of errors made in each task are converted to information measures, they agree very closely with the task difficulties as computed by a direct summation of the information required to be processed by the operator for each task.

In a fourth experiment with the model, the information content of seven factory jobs was evaluated. These jobs were in most cases very lightly loaded with mental work. A comparison was made of the total information required to be processed by the operator in each job per cycle of operation. The ranking of these jobs agreed, as shown in Table 2, with the independent ranking made by conventional job evaluation procedures. This latter ranking was made by the Industrial Engineering department of the plant in which the jobs were located. A discussion was held with the plant Industrial Engineering Department concerning the rather large range of the information measures compared with the job evaluation measures, particularly for job 7. It was pointed out by the plant Industrial Engineer that the job evaluation rating serves the company as a means of classifying jobs into one of many wage brackets. This leads to a very strong tendency to compress the scores to the median. The job evaluation for job 7 is already near the highest possible wage classification, and the "compression-effect" may be severe.

Another comparison of this same type was made in a second plant with the results shown in Table 3. The

TABLE 2

Comparison of Information Content Analysis and Job Evaluation

Job Number	Information		Job Evaluation	
	Measure (bits)	Rank	Rating	Rank
1 2 3	4.50 Information 4.5 Average 3.0 4.0	3	(Only average rating of jobs 1, 2, 3 available) 430	3
4	4.63 3.32 2.0 Average	5	386 (Only average rating available)	5
5	4.79	2	436	2
6	3.72	4	414	4
7	15.56	1	510	1

TABLE 3

Tabulation of Task Difficulty as Determined by Information Analysis and Compared with Rating by Conventional Analysis Procedure

Job	Information Analysis	Job Evaluation
IBM Clerk (female)	4.58 bits	57
Bag Machine Operator (female)	9.54	68
Pressman (male)	7.48	88
Ink Maker (male	6.47	81

single discrepancy was discussed with the plant Industrial Engineering Department. Here it developed that the worker in describing an important portion of her work, not being performed at the time the study was made, included most of that of her supervisor.

These results are extremely encouraging, and an extensive research program is being planned to develop the necessary data for complete substantiation and to make the techniques more generally useful for measurement of task complexity. Because the cross-disciplinary nature of this effort requires the talents of many fields, it will continue under the direction of a newly organized group at Washington University in St. Louis, Missouri. This organization called the Human Factors Research Group, is constituted of members of the faculties of the Medical School, the Psychology Department, Electrical and Industrial Engineering Departments and Mathematics Department.

The immediate objectives of the research in this area are to develop analytic expressions for all of the information factors and to determine the compatibility and dependency between the factors.

For example, experiments are being designed that will incorporate all of the factors as variables; psycho-physical testing and research are being planned to permit analytical determination for those factors where there is not yet a suitable relationship; and computer programming is planned to test the adequacy of the decision model, and to develop other decision criteria.

Research is also being planned to develop those human factor capabilities which are necessary for the proper application of the model; these are generally in the area of determining maximum channel capacities.

INDUSTRIAL ENGINEERING APPLICATIONS

The information content procedures described thus far have been largely those of analysis, and as such the application to job evaluation is evident. These same measures however, have important application in job synthesis or design and in selection and training for the work after job design is completed.

For example, the existence of a taxonomy for work complexity, which is evolving from this research, would provide the basis for testing and selection of job applicants. The degree to which particular factors are present in a job determines the capabilities which must be possessed by the successful operator.

The training program necessary for a given level of proficiency in a job can be evaluated by a comparison of the information required to be processed by the operator with that found to be possessed by the operator when first exposed to the task. Alternatively this evaluation can be approximated in advance of actual testing by accumulated data from typical operators when learning and performing tasks with equivalent information content.

It is recognized that these latter applications must await the accumulation of sufficient data on the normal information handing capability of large groups of operators for each of the information factors before general extrapolation can be justified.

The area of job design is one offering tremendous potential for fruitful exploitation of the information content approach. A study of the objectives to be performed in a job, combined with the inputs to the worker, leads to a measure of the minimum amount of worker effort required to perform the job satisfactorily. This measure when compared with the information actually processed by the operator permits an estimate of the improvement that may be expected by proper job design. If a large improvement is possible, engineering effort in job design should prove worthwhile. Alternatively, it may appear that the job is of such a nature that it would best be automated. The need for automation could result either because the job requirements are too severe for optimum human performance, or because the job is too lightly loaded and easily automated.

SUMMARY

The information content analysis approach to the study of task complexity provides a quantitative means of evaluating the difficulty or complexity of human work in areas where no such evaluation technique has been generally available. The Industrial Engineer is thus provided with a new and powerful aid in his evaluation, measurement and synthesis of human work, particularly for areas requiring exercise of mental capabilities.

While there is still a considerable amount of research required for information content analysis to become generally applicable, these areas of research all appear to be amenable to solution.

Several findings of the preliminary research are believed to be of immediate benefit to Industrial Engineering. Specifically, there are available measures for such items as the relative value of advance information to decrease unknown probabilities; the value of decreasing or removing extraneous stimuli; the expected improvement in proper design of choice situations; and the difficulty to be associated with discriminations between stimuli of similar appearance. These and other determinations can be provided with a quantitative measure where only subjective evaluation has prevailed.

Typical of the job analyses which should be benefited

by the information approach, for example, are those of a quality control inspector, a trouble shooting specialist, a pilot, and a radar observer. These jobs have two underlying aspects in common which are believed to be important to the successful use of information content analysis. These are:

1. Reasonably well defined stimulus-response categories.
2. Work which requires mental, rather than purely physical capacity.

Further application of the information approach to work analysis can provide, first of all, a taxonomy for describing work complexity. Secondly, techniques can be developed for evaluating learning difficulty when synthesizing new tasks. And thirdly, the information approach provides criteria for evaluation of man's efforts in the man-machine system; this in turn permits comparison between man and machine. Thus, not only may optimum work design be expedited but realistic rates of human activity can be established within the bounds of prescribed errors and prescribed mental and physical exertion on the one hand, and boredom on the other.

Further development of the concepts resulting from the information approach should lead to other applications of human behavior measurement where probabilities, interactions and noise are important aspects of the problem.

REFERENCES

(1) Alluisi, E. A., and Muller, P. F., Jr., "Verbal and Motor Response to Seven Symbolic Visual Codes: A Study in S-R Compatibility," *Journal of Experimental Psychology* 55, pp. 247-254 (1958).

(2) Becker, G. M., "Sequential Decision Making, Wald's Model and Estimates of Parameters," *Journal of Experimental Psychology* 55, pp. 628-636 (1958).

(3) Bricker, P. D., "Information Measurement and Reaction Time, A Review," *Information Theory in Psychology*, edited by Quastler, pp. 350-359, Free Press, Glencoe, Illinois, 1955.

(4) Broadbent, D. E., "Information Theory and Older Approaches in Psychology," *Proceedings of XV International Psychology Conference*, 1957.

(5) Crossman, E. R. F. W., "The Measurement of Discriminability," *Quarterly Journal of Experimental Psychology* 7, pp. 176-195 (1955).

(6) Leonard, J. A., "An Experiment with Occasional False Information," *Quarterly Journal of Experimental Psychology* VI, pp. 79-85 (1954).

(7) McGill, W. J., "Isomorphism in Statistical Analysis," *Information Theory in Psychology*, edited by Quastler, Free Press, Glencoe, Illinois, 1955.

(8) Middleton, D., and Vanmeter, D., "Modern Statistical Approaches to Reception in Communication Theory," *Transactions IRE Professional Group Information Theory* 4, pp. 119-145 (1954).

(9) Pierce, J. R., and Karlin, J. E., "Reading Rates and Information Rate of the Human Channel," *Bell System Technical Journal* 36, pp. 497-516 (1957).

(10) Poulton, E. C., "Measuring the Order of Difficulty of Visual-Motor Tasks," *Ergonomics* 1, pp. 234-239 (1958).

(11) Quastler, H. (Editor), *Information Theory of Psychology*, Free Press, Glencoe, Illinois, 1955.

(12) Quastler, H., "Studies of Human Channel Capacity," Three Survey Papers, *University of Illinois Control Systems Laboratory Report R-71* (1956).

(13) Quastler, H., and Wolff, V. S., "Human Performance in Information Transmission, I and II," *Control Systems Laboratory Report R-62*, University of Illinois, Urbana, Illinois (1955).

(14) Ross, Donald K., "Information Concepts in Work Analysis," Doctoral Dissertation, Washington University Sever Institute of Technology, 1960.

(15) Shannon, C. E., "A Mathematical Theory of Communication," *Bell System Technical Journal* 27, pp. 379-423 (1948).

PROFESSOR OF INDUSTRIAL ENGINEERING

Ph.D. degree. Teaching and Industrial experience required. Operations Research specialization preferred. Salary appropriate to qualifications. Department of Industrial Engineering, Syracuse University, Syracuse 10, New York.

MANAGEMENT CONTROL SYSTEMS

The Proceedings of a Symposium Held at System Development Corporation, Santa Monica, California —July 29-31, 1959

Edited by Donald G. Malcolm, *Operations Research, Inc.,*

and Alan J. Rowe, *System Development Corporation;*

General Editor: Lorimer F. McConnell, *System Development Corporation.*

This extraordinary collection of papers covers many aspects of the management control problem. Twenty-seven experts in the field of management, operations research, and computer systems consider the problem and exchange ideas on developing modern management controls. Not only does the book cover the present "state of the art" in management system design, it also discusses both the short-range and the long-range future of management control systems and describes current research in the field.

1960 375 pages Illus. $7.25

Order from: American Institute of Industrial Engineers 32 West Fortieth Street New York 18, New York

SEMTAR, Automatic Electronic Motion Timer

by **STANLEY M. BLOCK**

Associate Professor of Production Management, Graduate School of Business, University of Chicago

DURING recent years there has been a noticeable paucity of thorough research programs in efficient workplace design and motion time analysis. Apart from scattered graduate student theses and dissertations, the main efforts seem to be related to development or refinement of certain predetermined motion time data systems (12) and some investigations of the physiological costs of work (11).

There are probably at least two major reasons why research in this area has been minimal:

1. Recent emphasis in Industrial Engineering has been focused on systems analysis rather than micro-analysis.
2. Instrumentation for thorough and precise motion time research is painfully inefficient.

Few would deny the importance of systems analysis or the value of techniques such as simulation, queueing theory, inventory models, probability statistics, and decision theory. We must not, however, lose sight of the importance of fundamental investigation of factors which can lead to more optimal job design and accurate work measurement.

NEED FOR BETTER INSTRUMENTATION

The lack of efficient instrumentation for careful and thorough motion time research has been, no doubt, especially apparent to those who have worked in this area. The modern researcher recognizes the large amount of data required to test and validate hand motion hypotheses. Statistical theory has reminded us of the need for large samples if we are to be confident that a significant difference exists in the time required to perform a task under slightly modified conditions. In addition, we need to differentiate between the effects of individual differences, learning, effort level, etc. as distinct from the variable under investigation. In short, we need thousands or tens of thousands of time values to arrive at satisfactory conclusions even in a modest experiment.

CRITERIA OF EFFECTIVE INSTRUMENTATION

Techniques and equipment for hand motion research should be evaluated in terms of these criteria:

1. Identification of the motion or work element performed.
2. Consistent and easy establishment of boundaries between successive motions or work elements.
3. Accurate determination of performance time for each motion, excluding observer reaction time and electro-mechanical response times.
4. Ability to record individual elapsed time values for short (millisecond) and sequential time intervals.
5. Recording media should ideally permit mechanical or electronic translation and statistical computation by available commercial equipment.

This article will first briefly describe previously disclosed equipment for hand-motion research and attempt to evaluate the advantages and limitations of each technique with respect to the foregoing criteria. It will then describe the operation and construction of SEMTAR, (Sequential Electronic Motion Timer and Recorder) which possesses, I believe, unique advantages for motion time research.

In a few words, SEMTAR performs in the following manner. Once the workplace is properly equipped with transducers (such as photoelectric cells, microswitches, contact plates, etc.) to divide the repetitive work cycle into elements or motions, SEMTAR will continuously record on high speed punched tape the identification code and elapsed time for each successive work element performed. This punched tape can then be used as input for automatic interpretation (on a tape controlled typewriter), or translation (to punched cards or magnetic tape), or direct statistical computation (on a paper-tape-input electronic computer).

EXISTING RESEARCH TECHNIQUES

Gilbreth used a motion-picture camera to record the hand motion sequence and the technique of counting frames (successive pictures) to establish the time actually taken by a specified operator to perform a specified motion or series of motions during the recorded cycles. Micromotion study (8), as Gilbreth named this technique, has three major shortcomings for research:

1. The analyst must make arbitrary decisions which are not always consistent as to when (which frame) a specified motion has begun or been completed.
2. The accuracy of measurement is limited by the speed of the camera, usually 1000 frames per minute or 60 milliseconds between frames. These intervals are too high a percentage of the elapsed time for short motions, such as grasp or position.[1]
3. The analysis time and cost required to collect thousands of individual motion time values by film analysis (counting frames) is almost prohibitive.

KYMOGRAPH

Barnes partially solved two of these problems by his invention of the kymograph (1, p. 188). He instrumented the experimental workplace with certain transducers, principally photoelectric cells and microswitches, which

[1] Increasing the camera speed makes it more difficult to decide when one motion (such as "move") has ended and the next motion (such as "position") has begun.

were activated by the operator as he performed various motions in the experimental work cycle. These transducers were connected electrically to a strip chart recorder, where three or more pens traced continuous lines. The occurrence of a specified motion or motion combination is indicated by an offset in one or more of the penned lines. The elapsed time for that motion is determined by measuring the length of the offset, which is then converted to a time interval by dividing the measured distance by the constant speed of the chart beneath the pen, expressed in inches per minute.

The kymograph has several distinctive advantages over micromotion analysis for motion research, along with some limitations. One major advantage is the precise, or at least consistent, determination of end points for various parts of the work cycle, because an electromechanical device has been substituted for human judgment. Whereas different analysts will often derive different motion time values from the same strip of micromotion film, because of differing judgments as to which frame depicts the end of a specified motion, consistency in the determination of motion time values from kymograph charts is determined by accuracy in measuring lengths of lines.

A second distinct advantage of the kymograph over movie film analysis is in the accuracy of measuring the time interval. In film analysis one is limited to integer multipliers of the camera speed, resulting in step values of 60, 120, 180, etc. milliseconds for 1000 frames per minute, the usual speed. In contrast, the kymograph can be built (or modified) for any desired rate of paper speed, so distances (and time) can be determined as accurately as desired.

There is, however, an accuracy limitation with the kymograph which is determined by the response lag of the electromechanical system of transducer and recorder. The response time of microswitches, relays, and pen operating solenoids can be several milliseconds, depending upon design factors (9). The seriousness of this problem is reduced, however, by recognizing that the time lag at the end of a period compensates (in part, at least) for the time lag at the beginning of a period. So we are specifically concerned with variations in time lags between the "on" and "off" transitions of transducer recorder, the variation between different kinds of transducers used in the same experiment, and cycle to cycle variations in time lag with the same transducer.

A more important limitation of Barnes' kymograph is in the number of different motions or work elements which can be measured for a given cycle. Ideally each transducer should be connected to a separate recording pen, so that we can identify the motion associated with the offset line. Even a simple cycle should usually be divided into four elements, such as reach, grasp, move, and dispose, which become eight elements for simultaneous two hand cycles. We may, however, economize in the number of pens required by combining offsets of two pens (1, p. 189) or by measuring the time between successive offsets as distinctive motions (such as reach or move) (3).

The major problem which the kymograph has failed to solve is the tremendous amount of manual labor required to interpret the charts, by measuring line lengths and converting to time, and to translate the data into machine language form, such as punched cards or tape, magnetic tape, etc., for subsequent statistical computation and analysis. Each work element of each cycle for each subject under each experimental variation in the cycle must be carefully measured, manually recorded, and manually translated by keyboard into machine language. If sufficient data are collected to overcome or recognize random variations in element performance time, differences due to practice and effort of each subject, differences between subjects, and enough variations in the variable to develop general conclusions, the task of data collection and analysis is almost overwhelming. This problem is common to both the kymograph and micromotion technique.

ACCUMULATION CLOCKS

Another approach to simplifying the recording and analysis of motion time is the Universal Motion Analyzer developed at the University of Wisconsin (10). This device is limited, at least in published information, to comparison of travel time (time to move from one switch to the next) with manipulation time (time spent twisting, pushing, pulling, etc.). Time data are accumulated on two electric clocks with solenoid operated clutches. Once the experimental run is started, elapsed time is automatically divided between the two clocks by the contact of the subject's hand on successive switches.

The use of two or more accumulating time electric clocks has been extended to a wider variety of motion cycles using other transducers by McClure (6) and others. The average time for a motion is determined by dividing the total time on each clock by the number of cycles or repetitions recorded.

Accumulating clocks save a large amount of analysis time, but they also lose important detail. We have no record of individual motion time values. Our total may include individual times which are unusually long (fumbles) or unusually short (incomplete motions) and which may seriously affect the average time. Also, good statistical analysis requires a measure of the variability of values within a population, as well as the mean. Accumulating clocks do not provide information from which we can compute the variability of the individual time values.

A further limitation of the accumulating clocks is the time lag of all electromechanical devices which may introduce inaccuracies into the data.

ELECTRONIC TIME RECORDER

A major step forward in accurate timing was the de-

velopment of the Electronic Time Recorder by Buffa and associates under Ralph Barnes at UCLA (4). The ETR is an all electronic device which generates an electrical signal of 10,000 cycles per second. This timing signal is switched from one electronic counter to another by electronic switches (flip flops) which are activated by the subject's contact with metal objects at the grasp and release position. There are five electronic counters for timing five different events, and five associated mechanical counters which record the number of times that counter has been activated (the frequency of occurrence of that event).

The main limitation of the ETR is that, like the accumulating clocks, there is no provision for continuous recording of the actual time for each performance of each motion or element. Only total element times, including any fumbles or incomplete motions, are available, which must be divided by the recorded frequency of occurrence to get the average element time values. And these values must be manually recorded by an observer and later transcribed into machine language (punched card or tape) before they can be processed by tabulating equipment or electronic computers.

UNOPAR

Prior to the announcement of the Electronic Time Recorder, Nadler and Goldman of Washington University announced development of the UNOPAR, Universal Operator Performance Analyzer and Recorder (7, pp. 58-65). This elaborate and complex recorder was designed to do more than simply measure the elapsed time of specified motions or cycle elements. UNOPAR attempts to record continuously (in three dimensional coordinates) the location, velocity, and acceleration of one hand at all times throughout the work cycle. Nadler has applied the Doppler effect to hand motions, fixing a small ultrasonic speaker (20,000 cycles per second) on the hand and measuring small changes in the observed frequency due to movement of the hand toward, or away from, three microphones placed on X, Y, and Z axes at the periphery of the workplace. The change in observed frequency is proportional to the velocity of the hand, resolved into three directional components. This velocity is differentiated electronically to determine the acceleration or deceleration of the hand and integrated for its displacement or location.

As Nadler reports (7, pp. 61-62), UNOPAR, after several years of development, still possesses the following problems which limit its present usefulness:

1. The cost and size of the equipment.
2. No clear-cut boundaries between successive motions.
3. Time and cost of interpreting large quantities of data which are developed in analog form and graphically displayed.
4. Problems of identifying finger movements as distinct from hand motions.

There is little doubt that UNOPAR has many advantages in analyzing the characteristics or large displacement motions, like reach and move, especially if one is interested in studying the patterns of acceleration and velocity throughout the long movement.

For general motion research, however, one is interested in the time required to accomplish a motion, element, or cycle as a comparative index of work content, learning, effort, fatigue, interaction, etc. If significant time differences are discovered, we are often satisfied if we can discover the relationship between motion time and the variable or variables under study. If we wish to delve deeper into the physiological or psychological causes, other experimental methods and recording instruments may be required.

TRIAXIAL ACCELEROMETER

Another approach to the detailed study of large motions, especially the measurement of acceleration and velocity, is a system which would use a triaxial seismic accelerometer, attached to the hand or other body member of the subject (5). The proposed system, which was investigated but never developed by the MTM Association for Standards and Research, would require complex equipment to compensate for the effects of gravity with different orientation of the accelerometer (fastened to the subject's hand or wrist) during the motion. Further problems arise from the need to combine the acceleration vectors into a resultant acceleration, and the need to convert analog signals to digital data, with inherent loss of accuracy.

Like UNOPAR, this proposed system would be unable to provide us with usable motion time data in accurate and readily used form.

SEMTAR OPERATION

Careful analysis of existing equipment and techniques suitable for hand motion research has shown the need for a time recorder that is both accurate and efficient. This need was forcibly brought home to the author when he carried out a research project in 1956 on simultaneous hand motions, using modifications of both the micromotion and kymograph techniques to collect data. The micromotion technique was improved by taking plan view pictures from an overhead scaffold, by using a mirror to show eye motions as well as hand motions, and by clearly indicating the end points of motions with visible light bulbs activated by electromagnetic transducers (3).

But the task of extracting time values from the films and strip charts for 10 subjects, over 10 learning periods, using 12 different cycles, with cycles divided into 4 elements for each hand, and then making a limited number of statistical computations, was very time consuming and expensive.

The seriousness of the problem led the author in 1956 to consider possible new approaches, to search for help in

electronic design[2] and finally to the development of SEMTAR (Figure 1), Sequential Electronic Motion Timer and Recorder (2). It, too, has some limitations, but I believe it will be of great assistance in conducting the motion research which is sorely needed.

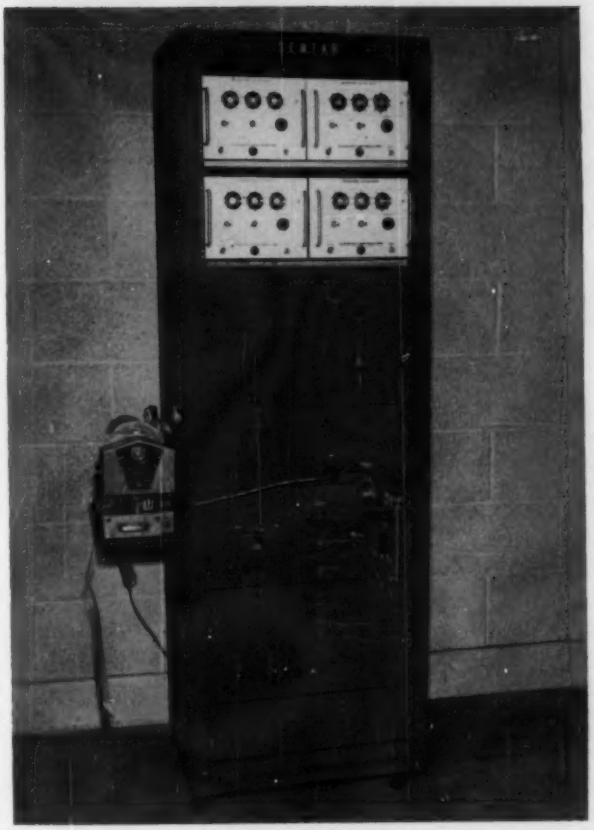


FIGURE 1. SEMTAR.

CHARACTERISTICS

Probably the outstanding feaure of SEMTAR is its ability to automate the recording of motion times or other sequential events in a machine language media (punched tape) which can be machine processed for complete listing of data, on tape controlled typewriter or tabulating equipment, or for statistical computations on tabulating equipment or electronic computers.

In addition SEMTAR possesses eight other important characteristics (13):

1. Measures short intervals to an accuracy of 0.001 second or less.
2. Excludes observer reaction time and errors by use of transducers to mark the end point of motion elements.
3. Begins timing of each element with a zero clock reading, thus eliminating the need to subtract successive clock readings.
4. Automatically identifies by code number each timed event.
5. Records data (element identification and time) on 5 channel or 7 channel punched tape.
6. Can simultaneously time and record two related work cycles, such as symmetrical two handed motion patterns.
7. Times and records sequential elements with minimum duration of 0.10 second for most work cycles, 0.15 second minimum duration if used to determine separate times for left hand and right hand simultaneous motions.
8. Element identification codes and time values are displayed visually.

INDIVIDUAL TIME VALUES

By recording the actual performance time for each motion or work element of each cycle, the analyst can accurately determine the frequency distribution, as well as the mean, of performance times for each work element as performed by each subject, under each experimental condition, and at each stage of learning. This complete record permits the exclusion, if desired, of extremely high or low values which may have been caused by operator fumbles, incomplete performance of an element, etc. Individual time values also permit important statistical computations of standard deviations and tests for significant differences in means or variance.

INSTRUMENTATION

The major requirement in the use of SEMTAR for laboratory or industrial timing is that the workplace be equipped with appropriate transducers by which SEMTAR can sense the duration of the various work elements in the work cycle. Common transducers which are easily connected and do not interfere with natural performance of the work cycle are photoelectric cells, microswitches, and contact antennae. The action of these transducers is equivalent to closing a switch for the duration of the event, and SEMTAR measures the length of time that the switch is closed (transducer is operative).

ELEMENT IDENTIFICATION

Provision is made to connect six or more transducers to SEMTAR so that the repetitive work cycle can be divided into six or more elements. In addition, SEMTAR is designed to measure the time intervals between the activation of successive transducers, so that work elements can be timed where none of the transducers are on.

An odd digit code number is preassigned to each transducer which is to be activated in the work cycle, and this code number is recorded on the punched tape in conjunction with the corresponding on time for that transducer. Typical work elements measured by transducer on time would include grasping an object, assembly of objects,

[2] Grateful acknowledgement is made to the Institute of Technology and the Graduate School, University of Minnesota for providing funds for development and construction of SEMTAR. Acknowledgement is also made to James Thornton and Robert Howard for their assistance in logical and circuit design, and to Richard Beggs and James Reynolds for their assistance in construction of SEMTAR. Financial aid for current refinement and application of SEMTAR is provided by the Ford Foundation through the Graduate School of Business, University of Chicago.

FIGURE 2. SEMTAR Recording Motion Data.

use time for a tool, engagement or manipulation of a machine control.

In addition the work cycle would normally be divided so that alternate work elements occur between these periods of transducer activation. Such work elements would be preassigned even numbered codes and would be appropriate for work elements such as reach and move (carry), or other work elements that cannot be easily measured by operation of a transducer.

SEMTAR is designed, then, to automatically identify, time, and record a sequential series of repetitive events. Although these work elements would normally be performed in a fixed sequence (e.g., 1, 2, 3, 4; 1, 2, 3, 4; etc.), a research subject might, if not constrained, alter the sequence in which he performs the work elements, or repeat certain parts of the cycle due to fumbles, etc. For this reason, SEMTAR has been designed to identify each odd numbered work element by the activation of the specific associated transducer, without restraint as to the previous work element, and each even numbered work element as that non-activating event which normally follows the activation of a specified transducer.

APPLICATION EXAMPLE

The operation of SEMTAR can be illustrated with a simple operation (Figure 2). Metal pegs, kept in a pan, are to be inserted, one at a time, into a hole of corresponding size and shape and released. The cycle can be readily divided into 4 elements:

1. Grasp one peg from pan of jumbled pegs.
2. Carry peg to hole.
3. Position, insert, and release peg.
4. Reach to pan for next peg.

Work elements 1 and 3 can easily activate appropriate transducers, such as photoelectric cells whose beam is interrupted by the hand at the grasping and inserting areas. Or if the pegs are metal and lie in a metal container, a conductor can be connected from an input circuit within SEMTAR to the metal pan. When the subject touches any of the pegs in the pan, the transducer is triggered to the on state and remains so until the subject has gained control of (grasped) one peg and begins to move it from the pan. SEMTAR can thus determine the actual time taken by the subject to grasp one peg, and these time values can be identified by element code Number 1.

Performance times for element 3, insert peg, can be determined by using either a photoelectric cell or another input circuit connected to a metal target surrounding the insertion hole. The transducer will indicate the elapsed time from the instant the peg in the subject's hand first touches any part of the target until the peg has been inserted and released.

Elapsed time for element 2, carry peg, is automatically measured and recorded as the time between completion of grasp peg (element 1) and the beginning of insert peg (element 3). Similarly, element 4, reach for peg, is the elapsed time between completion of insert peg, (element 3) and the beginning of grasp peg (element 1).

SEMTAR will time and record actual performance times for each element of each cycle as long as the tape punch is turned on, and unpunched tape is available. These individual time values permit computation both of the mean and variance (or standard deviation) for each element of the cycle. As experimental conditions are varied, similar data can be collected, analyzed, and compared with original data.

Experimental design might call for a measurement of the learning curve. Then SEMTAR can sample performance times for the same subject on successive hours and days of practice on the same operation. Or if we desire to measure individual differences, we can time different subjects on the same work cycle, noting whether or not individual differences affect performance times of all elements to the same degree. If we are interested in the effects of peg size or shape, of workplace layout, of allowances (size differential) between peg and hole, or other variables, we can gather a large quantity of detailed data economically.

TIMING SIMULTANEOUS EVENTS

In addition, SEMTAR is designed to simultaneously time the performance of each work element by each

hand, if the work cycle is designed to use both hands in a symmetrical manner. Suppose, for example, that we consider the operation previously described, except that we have 2 pans of pegs, 2 insertion holes, and pick up one peg with each hand, to be carried and inserted in the separate holes. Even though both hands would perform the cycle in the same average time, the performance times for individual work elements would probably be different for the two hands, and these differences could be determined from SEMTAR data. We can also compare performance time for a two handed operation with a similar one hand cycle.

RECORDING MEDIUM

One of the outstanding features of SEMTAR is that data are recorded in a machine language medium. The punched tape output can be used as input to available commercial equipment for translation to readable form or for computation by statistical formulae.

As discussed previously, other existing techniques and equipment for motion research require manual interpretation of micromotion films or kymograph charts, or at least visual reading and manual recording of numerical data (either printed or displayed). To use tabulating equipment or electronic computers, a person must use a keyboard, with consequent expense and risk of error, to translate handwritten numbers into punched card, punched tape, or magnetic tape form.

Punched tape was chosen as the recording medium for SEMTAR because it seemed the most suitable for typical conditions. A tape punch is less expensive and more portable than a card punch or magnetic tape recorder. It records at a faster rate (3600 characters per minute) than most card punches, but not as fast as magnetic tape recorders. Punched tape can be easily read and translated by a tape controlled typewriter for visual scanning of data, if desired. Punched tape also serves directly as input to many electronic computers, or can be automatically translated into punched cards or magnetic tape by existing commercial equipment.

For those not familiar with punched tape systems, there are three different code systems in commercial use: the 5 channel (Teletype), the 7 channel (Univac), and the 8 channel (IBM). The pilot model of SEMTAR uses a punch which can handle either 5 channel or 7 channel tape, and can be converted to appropriate coding by accessible switches and plugs. Actually, 5 channel code is adequate for all numerical information (as recorded by SEMTAR), but this usually requires translation into punched cards to be acceptable to a computer. If a computer which accepts 7 channel paper tape as input is readily available to the user, SEMTAR should be connected to punch 7 channel tape.

TIMING ACCURACY

The degree of accuracy required in timing an event is usually a function of the average time of the event and its variability. If, for example, event *A* lasts for about 5 minutes, with a variation from about 4.5 minutes to 5.5 minutes, measurement to the nearest 0.01 minute (3 significant digits) is probably adequate. If, on the other hand, event *B* averages 0.50 second, ranging from 0.43 to 0.57 second, measurement to the nearest 0.001 second (3 significant digits) would probably be desirable; greater accuracy than this might look impressive, but would seldom be significant in analyzing the results.

Timing increments of 0.001 second can be achieved by using an electronic oscillator that emits a master signal at a frequency of 1000 cycles per second. A 3 digit counter can accumulate these signals to record an elapsed time of 0.999 second, assuming the counter is reset to zero before timing each event. To time longer events we would need either a counter with greater capacity, such as 4 digits for 9.999 seconds, or a slower master signal, which could measure events up to 9.99 seconds at 100 cycles per second on a 3 digit counter.

MINIMUM ELEMENT TIME

Before we decide upon the oscillator speed and capacity of the counters, we should also examine the effect of read out time on minimum duration of recorded events. Read out time is determined by the number of digits recorded and the speed of the recording equipment. If we use a 3600 characters per minute punch, it will take 0.0167 second for each digit recorded. If we record one digit of identification code, e.g., "2" for element 2, plus 3 digits of time information, e.g., "563" for 0.563 second, plus one "end of word" code, e.g., "*A*", plus a synchronizing constant (equal to 1 digit), our read out time is 6 digits at 0.0167 second each, or 0.100 second total read out time. If we wish to record the elapsed time for two similar but simultaneous events, e.g., left hand grasp and right hand grasp, our read out "word" would be increased by 3 more digits of time information to 9 characters at 0.0167 second per character or 0.150 second of read out time.

How is this related to the minimum duration of recorded events? We must read out the elapsed time for each recorded event before a counter can be reset to zero and used again. The pilot model of SEMTAR uses pairs of counters, one pair for each hand, so that the accumulated time on one counter can be read out after that event is completed and while the time for the next event is being counted on the other counter. If, for example, it takes 0.100 second to read out the data for event 1 from counter *A*, event 2, which is being recorded on counter *B*, should continue at least 0.100 second so that counter *A* will be read out and ready to time event 3, etc.

If this minimum event time is too great for certain experimental conditions, SEMTAR can be modified in one of three ways. The most effective method would be to reduce the read out time by using a faster punch or

magnetic tape. Faster read out would enable us to record a large number of successive events, all of which are very short in duration. Alternative changes would be to use more than two counters, so that three or more counters would be counting and then read out in succession, rather than alternating between a pair or to read out counters into a magnetic buffer memory and then to punched tape. These solutions still require that the average element duration be greater than the read out time, but permit some element times to be smaller than the read out time. However, use of more counters also requires that subelements of the work cycle always be performed in exactly the same sequence, or that a very complex control program be designed.

SEMTAR TECHNICAL DESIGN

The overall design of SEMTAR is shown in Figure 3, with a master clock, input section, electronic counters, identification tubes, read out control section, coder, amplifiers, and tape punch. In addition, direct current power supplies are required for all components.

MASTER CLOCK

Any stable frequency generator can be used for a master clock, although the frequency of the output should be related to the desired accuracy of measurement and should preferably be easily converted to common time units (seconds, minutes, hours).

The easiest source of electrical pulses of a constant frequency is the 60 cycles per second from the commercial alternating current supply. This speed, however, is too slow to adequately measure differences between time intervals that are relatively short because the time increments would be 0.0167 second.

The master clock now used in SEMTAR is a low

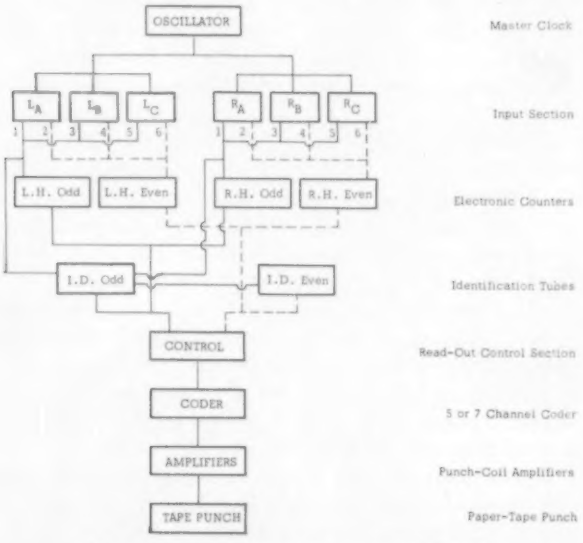


FIGURE 3. Overall Block Diagram (SEMTAR).

Oscillator Frequency	100 cps	1000 cps	500 cps
Indicated Time	2.41 sec.	0.241 sec.	0.482 sec.

FIGURE 4. Three Digit Decade Counter.

frequency R-C oscillator which can be set and turned accurately for frequencies of 100, 500, or 1000 cycles per second. Used with 3 digit counters, the 1000 cycles per second band permits us to count up to 0.999 second in 0.001 second increments (Figure 4).

Longer work elements can be timed by either decreasing the frequency of the master clock or by increasing the counter capacity. A single switch on the oscillator changes the frequency to 500 cycles per second, which permits timing of elements up to 2.000 seconds in 0.002 second increments. A further turn of the switch changes the frequency to 100 cycles per second, which provides 9.99 seconds capacity in 0.01 second increments on a 3 digit counter.

Longer work elements can also be timed by increasing the capacity of the counters. Because one set of counters must be held at the total count for the previous event until they are read out, only half of the total counting capacity can be used for counting at any instant. With the present capacity of 12 digits of counting capacity, only 6 digits are available for counting at a time. If we independently time two simultaneous events (e.g. left hand and right hand motions), only 3 digits of counter capacity can be used to time each event. However, if we are timing only one cycle of activities, we can feed our master clock signals into the 3 digit counter designated "Right Hand" (R.H.) and overflow into the "Left Hand" (L.H.) counter, giving us a 6 digit capacity.[3] Although this gives us greater accuracy than we would have if we slowed down the master clock, we do increase the number of digits in our read out word, thus increasing the read out time and increasing the minimum element time. Whether or not this is a disadvantage, depends upon the situation at hand.

Somewhat greater stability of the master clock could be obtained by using either a tuning fork or a crystal as the master frequency source in the oscillator. However,

[3] The read out sequence is: Identification code, Left Hand Time, Right Hand Time, End of Word Code; so higher order digits are fed from the Right Hand counter to the Left Hand counter to be read out before lower order digits.

the crystal controlled oscillator would have to be designed to generate a high frequency signal (about 3,000 to 10,000 K. C.) which would then have to be reduced to the desired clock frequency by using the overflow from one or more decade tubes in series.

COUNTERS

Electronic counters are faster, more accurate, and more easily read out than electromechanical clocks. Counters can be designed either on a binary or decile system. The decile system is preferable if we use punched tape or punched card output; the binary system can be more easily recorded on magnetic tape.

Decade counting tubes are the core of a decile counter. These tubes have ten cathode pins, in a circular pattern (Figure 4), any one of which can conduct current from the center anode. The tube is electronically reset to the zero position, prior to counting, and advances one pin each time an amplified positive pulse is received. As the first (digits) tube advances from 9 to 0, an overflow pulse advances the next (tens) tube one digit. Similarly, the tens tube overflows to the hundreds tube.

The final count on a decade tube is read out by connecting each cathode to a corresponding position in the scanner matrix, where it serves as one of the inputs to an "and" gate. The current carrying cathode, which is the one corresponding to the count received, is at a higher voltage than any of the other cathodes, due to cathode resistors, and permits a signal to pass through the corresponding "and" gate in the scanner to the coder, amplifier, and finally the punch.

INPUT SECTION

The input section has two important functions to fulfill:

1. Directing the master clock pulses to either the odd counter or the even counter, depending on whether or not one of the workplace transducers, corresponding to an odd numbered work element, is on.

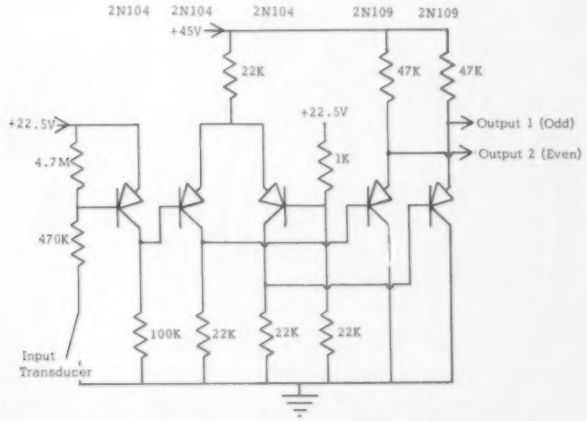


FIGURE 5. Input Circuits (1 Required for Each Transducer Input).

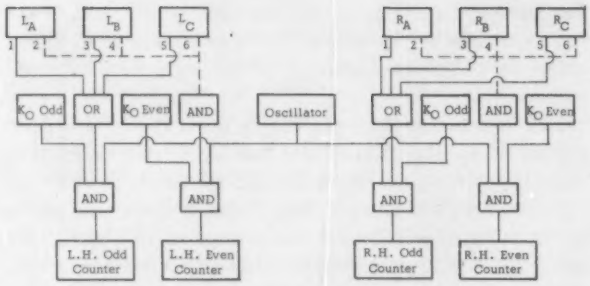


FIGURE 6. Input Block Diagram.

2. Providing proper signals to the identification section to identify the work element which is being timed by the counters.

Each transducer used as an input to SEMTAR needs an input circuit which can interpret whether the transducer is on or off. At the present time, there are six input circuits, three for each hand. More can be easily added, if found desirable.

Each input circuit is a buffered unistable flip flop (Figure 5), with an input connected to the corresponding transducer in the workplace through a jack on the front panel. When the transducer is off, it presents a high impedance to the flip flop, and the flip flop operates in its normal mode (transistors 2 and 5 conducting, transistors 1, 3, and 4 biased to cutoff). When the transducer which is connected, for example, to L_A (left hand, first input) is activated by body contact with a lead from SEMTAR, the L_A flip flop changes mode (transistors 1, 3 and 4 conducting, transistors 2 and 5 cut off) and remains in alternate mode until the body contact is removed, when it instantly reverts to normal mode. In normal mode, a positive voltage is provided on L_2 output, and zero voltage appears on L_1 output; in alternate mode, these voltages are reversed, providing an L_1 output signal. Similarly, body contact with L_B, L_C, R_A, R_B, or R_C antennae would provide signals on L_3, L_5, R_1, R_3, or R_5, respectively; otherwise these input circuits will provide output signals on L_2, L_4, L_6 and R_2, R_4, R_6.

The next stage of the input section uses these signals to direct the pulses from the master clock to either the even counters or the odd counters. Outputs L_1, L_3 and L_5 are fed as input to an "or" gate (Figure 6); if any one of the transducers is on, an output signal is provided to the next "and" gate, which permits the master clock pulses to be fed to the L.H. odd counter. As soon as the transducers are all off, the "or" gate no longer supplies a voltage to the next "and" gate, and the clock signals no longer are fed to the L.H. odd counter.

At the same time, the L_2, L_4, and L_6 outputs are fed to another "and" gate. If none of the left hand transducers are on, we are performing an even numbered work element and voltages will be supplied as L_2, L_4 and L_6, which give an output from this first "and" gate. This output permits the clock pulses to pass through

the second "and" gate and be fed to the L.H. even counter. As soon as one of the transducers is switched on, clock pulses are instantly cut off from the L.H. even counter.

In the same manner, we use gates to switch the clock signals from the R.H. even counter to the R.H. odd counter for work cycles using the right hand. The switching occurs at the exact instant when a change in transducer mode indicates the completion of one work element and the commencement of the next work element. For simultaneous (two hand) work cycles, the switching of signals between the pair of L.H. counters is independent of the switching of input to R.H. counters.

One further restriction is programmed into these circuits. We want to be certain that the previous reading on a counter has been read out, and that the counter has been reset to zero before we begin counting another work element on that counter. This requirement is met by connecting the K_0 cathode of the corresponding step tube, which controls read out, to the last "and" gates (Figure 6). When a counter has been read out and reset, the corresponding step tube is reset to the K_0 position, and the master clock signals can reach the proper counter.

IDENTIFICATION SECTION

The function of the identification section is to identify which work element is being performed and timed so that the proper numerical code can be placed on the read out tape to identify the corresponding time value or values.

In order to simplify the circuitry and minimize the read out time, SEMTAR now is designed with a single pair of identification tubes, an odd I.D. tube and an even I.D. tube (Figure 7). As with the counters, a pair is required so that one can remain set at the position corresponding to the work element which has been completed until it is read out, while the other I.D. tube is set for the work element then being performed and timed.

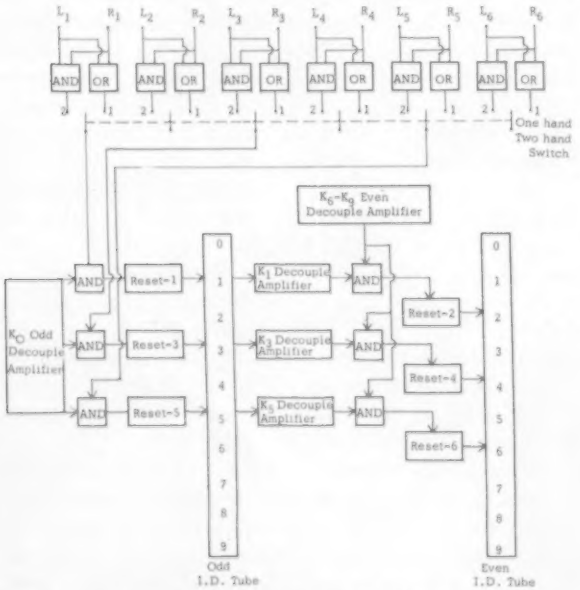


FIGURE 7. Identification Block Diagram.

Whenever transducer Number 1 is made operative by the worker, the odd I.D. tube is reset to the K_1 position, provided the previous data on the odd I.D. tube and odd counter have been read out and recorded, as indicated by the K_0 position of the odd step tube. In similar manner, activation of transducers Number 3 or Number 5 will reset the odd I.D. tube to K_3 or K_5 position.

This design frees the subject from any restraint in the experimental cycle which would require him to perform each work element in prescribed sequence. Although a fixed sequence of work elements might be normal, experience has shown that fumbles and other human errors cause certain work elements to be repeated more frequently than the rest of the cycle.

Identification of the even work elements is more difficult, inasmuch as none of the transducers are activated during these work elements. It is necessary, therefore, to identify an even work element by reference to the odd element which was just completed. We connect the K_2 cathode of the even I.D. tube to the K_1 cathode of the odd I.D. tube, through an appropriate decouple amplifier and a reset circuit (Figure 7). Similarly, we connect K_4 (even I.D.) with K_3 (odd I.D.), and K_6 with K_5. However, we must delay the resetting of the even I.D. tube until the identification and time for the previous even work element have been read out and recorded. This is accomplished by monitoring the activity of the step tube which controls the read out. By connecting the K_6-K_9 even decouple amplifier to "and" gates between the odd I.D. tube and the reset circuits for the even I.D. tube, even I.D. tube will not be reset until after the code number of the previous even work element has been read out and recorded.

One further section is required when we are timing motions of both hands in symmetrical work patterns. When the one hand-two hand switch is set in the two hand position, we delay the read out of the data and the resetting of the I.D. tubes until both hands have completed the previous work element. This is accomplished by sending L_1 and R_1 through one "and" gate, L_2 and R_2 through another "and" gate, etc., for two hand operation. Signals must appear on both inputs to an "and" gate before an output signal occurs which will initiate read out and change the I.D. tube.

READ OUT CONTROL SECTION

The read out control section programs the read out and the reset function of SEMTAR. This section must

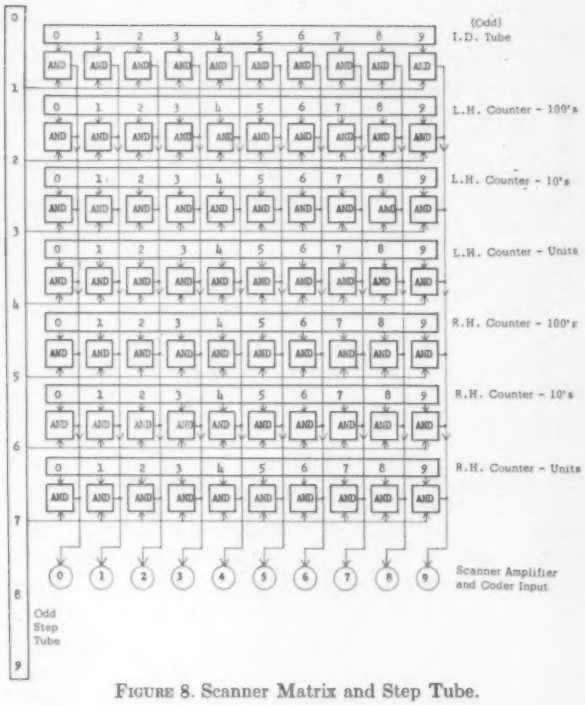


FIGURE 8. Scanner Matrix and Step Tube.

initiate read out at the end of each work element and must sequentially make and break connections from the I.D. tubes and counters to the coder amplifier punch section. Information must be supplied to the punch one digit at a time, in the proper sequence, and properly synchronized with the punch cycle.

The basic read out sequences of eight digits have been established as follows:

1. Identification code (1 digit).
2. L.H. counter time (3 digits).
3. R.H. counter time (3 digits).
4. End of word code (1 digit).

This read out pattern will be described before alternate patterns are discussed.

The circuitry used to read out data consists of two main components, a scanner section (Figure 8) and a read out control section (Figure 9). The scanner and decatron step tube function together like a 10 pole switch which can be advanced through 10 positions to read out up to 9 digits of information, one at a time. Two sets of scanner matrix and step tube circuits are needed, one to read out the odd I.D. tube and counters, and the other to read out the even I.D. tube and counters.

Each box in the scanner matrix (Figure 8) represents an "and" gate, which has a positive output if both inputs are positive at the same time. One input to the top row of "and" gates is provided by connecting all cathodes of the I.D. tube to these gates, one cathode (0 through 9) to each gate. The other input to the top row of "and" gates is provided by connecting the Number 1 cathode of the step tube to all of the "and" gates in the top row. The output of each gate in the top row is connected through a scanner amplifier to the corresponding input (0 through 9) of the coder. Thus, the cathodes of the I.D. tube are connected to the coder input when the step tube is conducting in the Number 1 position, and a signal will pass from whichever cathode of the I.D. tube is conducting to the corresponding scanner amplifier and coder input. In this manner we read out the proper digit from the I.D. tube to the coder.

Similarly the cathodes of the highest order (100's) counting tube in the L.H. counter are connected to the second row of "and" gates in the scanner matrix, and the Number 2 cathode of the step tube is also connected to all gates in the second row. The outputs of these 10 gates are connected through scanner amplifiers to corresponding inputs of the coder. When the step tube is conducting in the Number 2 position, the reading on the L.H. high order counting tube will be supplied to the coder input.

By connecting all cathodes of the other counter tubes to consecutive rows of "and" gates in the scanner, we can read out the I.D. tubes and all counter tubes in sequence, by advancing the step tube after each punching cycle.

The control section must include circuits which initiate

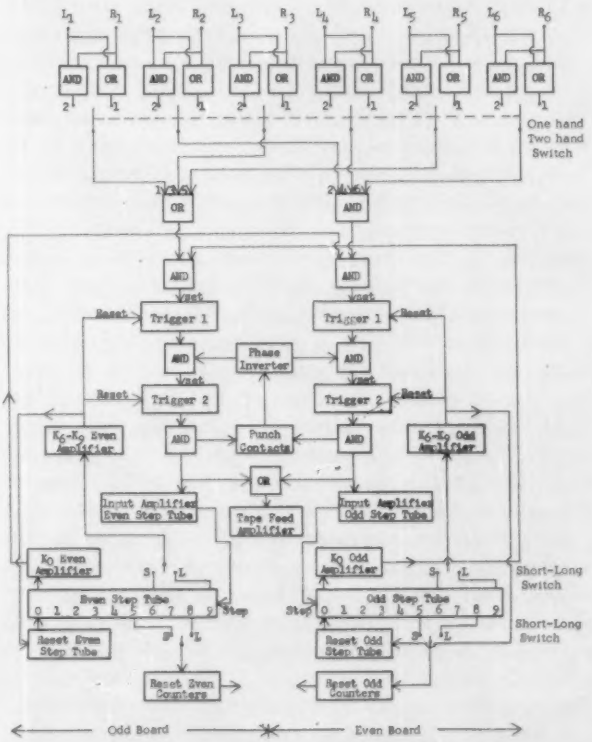


FIGURE 9. Read Out Control Section.

read out at the proper moment, advance the step tube for read out of successive digits, and reset counters and step tubes to zero position (Figure 9).

First consider the three conditions which must be fulfilled before read out, for example, of the odd counters begins:

1. The time work element (odd) must be completed.
2. Read out of the previous element from the even counters must be completed.
3. The punch must be ready to receive a coded signal.

We know that the odd work element is completed if the input circuits tell us an even work element has begun. An odd work element is completed when all transducers are off, as indicated by a signal through the 2-4-6 "and" gate (Figure 9). When we are timing *both* hands on similar and simultaneous work cycles (selector switch in "two hand" position), it is necessary that both the L.H. and R.H. input transducers be off, to show that both the L.H. and R.H. counters have completed their timing of the odd work elements.

The second necessary condition before permitting read out of the odd counters is that we have finished our read out of previous time values on the even counters. One way to monitor this situation is to ascertain the position of the even step tube. When read out of the even counters is completed, the even step tube is reset to the zero position (designated K_0) by the K_8-K_9 reset amplifiers.

Looking at even board on the read out control block diagram (Figure 9), we see two "triggers" and three "and" gates between the 2-4-6 "and" gate and the odd step tube. A signal will pass through the first "and" gate and "set" trigger 1 (turn it on) as soon as we have fulfilled the first two conditions, completion of the odd work element and reset of the even step tube to zero. The third requirement, that the punch be ready to receive a coded signal, is fulfilled by first inverting the negative synchronizing pulse from the punch, which comes before the punch is ready to receive a signal. This inverted pulse, together with an "on" signal from trigger 1 goes through the second "and" gate to set trigger 2. When the synchronizing pulse from the punch becomes positive, the output from trigger 2 will pass through the third "and" gate, be amplified by the step tube input amplifier, and will advance the odd step tube from K_0 to K_1 (position 1), thus connecting the odd I.D. tube to the coder so we can read out the identification code.

After the punch has recorded the first digit, the punch synchronizing signal becomes negative again and turns off the third "and" gate. However, trigger 2 stays on, and as soon as the punch signal becomes positive again, another pulse comes through the third "and" gate which advances the odd step tube from K_1 to K_2, so the second digit can be read out and recorded. Each punch cycle will advance the step tube one position, until all data are read out.

The number of digits read out, and their significance, depends on the operating mode of SEMTAR. The mode is determined by the cabling to the counters and by the position of the long-short switch. These modes are:

1. *Two Hand, Long Cycle*

This is the basic mode (described earlier) with an 8 digit read out, including 3 digits for the L.H. counter and 3 digits for the R.H. counter. Cabling to each of the four counters is direct from the input section. The switch is set to "long," which means that the counters being read out are reset to zero when their step tube reaches position K_8, and the step tube itself is reset to zero when it is at position K_9.

2. *One Hand, Long Cycle*

This is an alternate 8 digit mode used for one hand cycles when the minimum element time will be not less than 0.150 second. It provides 6 digits of time information for one hand (either left hand or right hand) in addition to the 1 digit I.D. code and a 1 digit end of word code. Cabling to the counters is such that clock pulses are always fed into the R.H. counters first and overflow to the L.H. counters. This permits the highest order digits to be read out first, progressing to lower order digits. The switch is set to the "long" position so that counters are reset at K_8 and the step tube is reset at K_9, as above.

3. *One Hand, Short Cycle*

If we are timing a one hand work cycle, or one in which the two hands work together on a common task rather than independently, and if the minimum work element time is between 0.100 and 0.150 second (or if 3 digits of time information are adequate), we can shorten the read out word to 5 digits instead of 8 digits. This is accomplished by counting only on the L.H. counters and by setting the long-short switch to short. In this latter position, the step tube resets the counters at K_5 and resets itself at K_6. This position of the switch also connects the end of word code to the punch when the step tube is at position K_5 rather than K_9 (which is not reached in short cycle operation). In this way, the read out cycle is shortened to 0.100 second.

CODER

In order to be as adaptable as possible to available commercial equipment for translation and/or computation of the coded tape information, the pilot model of SEMTAR can be set to punch either 5 channel or 7 channel paper tape.

On punched tape, each digit is represented by one or more holes in a column across the width of the tape, and consecutive digits are punched and read in consecutive columns. Standardized Teletype code is used for 5 channel operation, and Univac code for 7 channel operation. For example, the digit "two" is represented in 5 channel code by holes punched in position 2 and 4; the digit "three" requires a single hole in position one. In 7 channel code (only 6 punching positions are used for numerical data), the digit "two" is represented by holes in positions 1, 2, 3 and 4; the digit "three" is recorded by punches in positions 1, 2, and 3.

The coder transforms a signal received from the scanner matrix of the read out control section into proper code for tape punching. There are 10 lines connecting the columns of the scanner matrix with the coder input

(through individual scanner amplifiers). The coder merely distributes a single input signal, received from the scanner on lines 0 through 9 to one or more of the 6 punch amplifiers which drive appropriate punch magnets and permit appropriate holes to be punched. In 5 channel operation, for example, an input to the coder on lines 2 would drive the punch amplifiers for punch magnets 2 and 4. If the next digit read were a "three," only the first punch magnet would be energized.

In addition, a signal is provided to the tape feed amplifier each time a digit has been read and punched so that the tape will be advanced one column, ready to record the next digit.

Conversion of SEMTAR from 5 channel output to 7 channel output merely requires changing a plug from one socket to another, plus substitution of wider tape and tape guides.

PUNCH AMPLIFIERS AND PUNCH

The punch unit is mounted on the outside of the relay rack which contains the electronic components. This punch is made by Teletype, and operates at 3600 revolutions per minute. An eccentric on the driveshaft supplies mechanical power to drive any or all of the punch pins down on each revolution. The feed punch is driven down with each rotation of the shaft, but other punches are depressed only if their corresponding magnets receive a signal prior to the beginning of the punch stroke and are kept energized until the punch has pierced the tape. Synchronization signals are produced by contacts driven from the drive-shaft, and can be adjusted to energize and release the punch magnets at the proper time. This synchronizing signal is also fed to the read out control section to time the initiation progress of read out.

Although the driveshaft of the punch rotates continuously, data are punched, and the tape fed, in spurts, with one word (5 or 8 digits) recorded after the completion of each work element. Thus there is no waste of tape, and successive data words follow each other, separated only by the nonnumerical end of word code. The importance of this code can be seen, because all other data are numerical, and if there were a malfunction in read out, it would otherwise be impossible to note the error or decipher the data.

A second function of the end of word code is that it represents to a 5 channel tape controlled typewriter a tab stop. This advances the typewriter carriage so that successive data words will be typed in columns, if a typewriter translation of the coded data is desired.

USES FOR SEMTAR

It is hoped that the development of an accurate and efficient machine for collecting motion time data, SEMTAR, will encourage more universities, management consultants, and Industrial Engineering Departments in industry to conduct research in the problem areas of work design and measurement. I would like to suggest some needed research which seems important to me.

In recent years several systems of predetermined motion time data have been developed and made available to the public, including MTM (Methods-Time-Measurement), BMT (Basic Motion Timestudy), and Work Factor. Although most of these systems, when used by experienced applicators, seem to provide time standards of greater accuracy and versatility than result from time study, critics of this approach have raised some questions that as yet have not been satisfactorily answered by adequate research. These questions include matters of the validity of adding all possible combinations of element time data, the adequacy of procedures for determining normal time values for simultaneous hand motions, the effects of learning opportunity and length of cycle upon normal time, the effects of visual and mental requirements upon performance time, time values for "blind" grasp and/or positioning, and the exploration of possible further variables (such as direction of reach or move). In addition, attempts to compare data between systems or to validate individual systems (by persons not connected with the development or use of the system) have been very limited in scope.

Another fruitful area for research would be in the refinement and extension of various lists of "principles of motion economy." Many of these "principles" are stated in such general terms that application to specific work cycles leaves many questions unanswered. Two related areas of needed research, which are perhaps more suited to industrial experimentation, are the matters of fatigue and learning curves. Some published research raises serious questions as to the validity of the "typical output curve" which purports to show normal increases and decreases in rate of output during different hours of the working day. If a SEMTAR were connected to transducers on a variety of workplaces, it could be programmed electrically to sample cycle performance times (and output rates) at various times of the day and under various conditions. Such a study might also be longitudinal, to determine the effect of practice opportunity or lot size on typical cycle or work element performance time.

SEMTAR could also be used efficiently for time study purposes. The machine would accurately record actual element time values, leaving the observer free to concentrate on pace rating and observe carefully the work method being followed. Although I do not anticipate that SEMTAR will ever replace the stopwatch, I do believe it would be especially useful for research, for development of standard data, and for settling disputes between management and the union with regard to elapsed time of machine controlled or man controlled work elements.

SEMTAR can also be used for timing events outside of the field of production management. For example, it can measure and record response time or other activities

in applied experimental psychology. It could also be adapted for engineering or medical research to measure the length of time that certain temperatures, pressures, voltages, etc. exceed, or are less than, specified critical values.

REFERENCES

(1) Barnes, Ralph W., *Motion and Time Study*, Fourth Edition, John Wiley and Sons, New York, 1958.

(2) Block, S. M., "An Automatic Digital Recorder for Timing Sequential Events," *IRE Transactions on Medical Electronics*, September, 1959, pp. 157-159.

(3) Block, Stanley M., "Effects of Visual Requirements upon Certain Simultaneous Hand Motions, Ph.D. dissertation (University Microfilms, Ann Arbor, Michigan).

(4) Buffa, E. S., "The Electronic Time Recorder: A New Instrument for Work Measurement Research," *Journal of Industrial Engineering*, March-April, 1958, pp. 89-92.

(5) Karger, Delmar W., "Instrumentation for Automatic Data Processing in Motion-Time Research," *Journal of Industrial Engineering*, March-April, 1958, pp. 123-132.

(6) McClure, J. C., "An Exploratory Investigation of Some Aspects of Learning," unpublished M.S. Thesis at Ohio State University, 1951.

(7) Nadler, Gerald, and Goldman, Jay, "The UNOPAR," *Journal of Industrial Engineering*, January-February, 1958, pp. 58-65.

(8) Niebel, B. W., *Motion and Time Study*, Richard D. Irwin, Inc., Homewood, Illinois, 1958, Chapter 9.

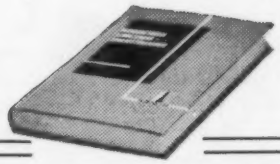
(9) Rand, C., "A Study of the Accuracy of Input-Devices Used in Work Measurement Investigation," unpublished M. S. Thesis, College of Engineering, UCLA, September, 1954.

(10) Smith, K. V., and Wehrkamp, R. F., "A Universal Motion Analyzer Applied to Psychomotor Performance," *Science*, 1951, Volume 113, pp. 242-244.

(11) Young, H. H., "The Relationship between Heart Rate and the Intensity of Work," *Journal of Industrial Engineering*, November-December, 1956.

(12) *MTM Research Studies*, MTM Association for Standards and Research, Ann Arbor, Michigan.

(13) "Newest Motion Timer and Recorder," *Factory Management and Maintenance*, September, 1958, pp. 162-163.



Save money, increase production efficiency

with these tested time-allowance methods

HERE are the principles of work measurement and motion identification essential to a system of predetermined motion times aimed at universal application.

The book brings you exact procedures and examples showing how time data are used to set standards either through direct study or through the use of elemental standard time data.

All time data are related to a unit of motion—called Basic Motion—which has clear-cut end points that may be applied to all body members.

BASIC MOTION TIMESTUDY. By **Gerald B. Bailey** and **Ralph Presgrave**, of J. D. Woods & Gordon, Ltd. 189 pages, 6 x 9, 56 illustrations, $5.00

Order from:
AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS
32 West Fortieth Street
New York 18, New York

- HOW FOREMEN CAN CONTROL COSTS
- TIMESTUDY FUNDAMENTALS FOR FOREMEN
- TIMESTUDY FOR COST CONTROL
- HOW TO CONTROL PRODUCTION COSTS
- HOW TO CHART TIMESTUDY DATA

Uncover HIDDEN PROFITS in your plant or shop with the—

5-volume McGraw-Hill

PRACTICAL COST CONTROL LIBRARY

By PHIL CARROLL, *1372 pages, 460 illustrations, only* $19.50

An expert on the subject, Phil Carroll, shows you exactly how to take on cost control problems—*and solve them*—at all levels in the plant or shop. Foremen, supervisors, engineers, timestudy men—all can use these specific facts, data, and methods to get on top of cost problems in quick order.

Starting right at the front-line supervisory level, this Library points out the foreman's responsibilities for costs—gives scores of helpful suggestions on such typical foreman cost problems as changing setups, training new men, handling rush orders, eliminating waiting time, scrap, and so on.

Timestudy techniques and applications

From the ABC's of timestudy, this Library leads you step by step through the standard-setting processes. Complete, practical explanations cover the entire timestudy procedure—how and where to start, building standard data, applying standards, and maintaining a complete incentive installation.

A full explanation of the total-conversion-cost method of control gives you tested means of boosting profit and plugging cost leads.

Order your Library from: American Institute of Industrial Engineers
32 West Fortieth Street, New York 18, New York

Some Legal Aspects of Computer Use in Business and Industry

by **ROY N. FREED**

Ballard, Spahr, Andrews and Ingersoll

FEW ENGINEERS designing and selling Electronic Data Processing (EDP) systems are aware of how the law affects their work. The law is an important factor, demanding as careful attention in many jobs as cost savings, tighter control, and increased efficiency. This article will explore how the duties of the EDP engineer are influenced by negligence law (1). Although that is only one of the many fields applicable, it is especially important because, as the name suggests, it tells who shall bear the loss in each case where injury to persons or property results from an accidental mishap or error. And EDP devices, like many other machines or methods of doing things, can be either the cause of such misfortunes or, under other circumstances, the means to prevent them.

The rules on how the cost of accidental damage will be borne can be of great benefit to some EDP engineers and can impose some additional work on others. Where EDP systems under design might fail to function properly in operation and cause injury, a desire to avoid the penalties of the law might require the inclusion in them of extra control features. There might be occasional situations where the user of the system would accept design compromises and risks of inconvenience in his own operations to avoid greater design costs, but will be unwilling to expose himself to lawsuits and their imponderable expense, when apprised of the danger. Doing a good job thus requires the ability to spot those situations in advance so that an intelligent decision can be secured on which course of action to take. This involves some familiarity with the legal rules that apply. Under those circumstances the law is a negative factor.

There will be many cases, however, where the introduction of an EDP device will help a company reduce its exposure to lawsuits. It is expected that manufacturers will offer an increasing number of those mechanisms with capabilities to spot, and even correct, accident-producing hazards which, if they eventuated as mishaps, would drag the guilty company into court. To the sales engineer, aware of this facet and able to make constructive suggestions to potential customers how the devices can be used, the law can be a valuable positive element. This approach requires a knowledge of the law.

This discussion will present the rules of negligence only in enough detail to help engineers recognize situations with legal significance. Since it is not intended to make engineers into lawyers, the mission will be considered accomplished if they are convinced of the value of getting legal advice on specific sets of facts.

EXAMPLES OF NEGLIGENCE SITUATIONS

A glance at some hypothetical EDP situations to which negligence law would apply will indicate the types of real life events behind the discussion of legal rules and procedure to follow. An explosion causing extensive damage to persons and property occurs in a chemical plant controlled by an EDP unit. A computer directed steel rolling mill runs amuck, injuring the employees tending it and damaging the plant. A commercial bank utilizing an electronic check processing and bookkeeping system refuses incorrectly to pay a check drawn by a business customer, causing him to lose a potentially profitable transaction. An airplane manufacturer fails to utilize an EDP system to predetermine the structural characteristics of its new models, and its craft are involved in serious accidents because of flaws. By error, a railroad classifying its freight cars by computer control designates a car containing fragile merchandise for humping, and thereby damages the goods. In a fully integrated business management system, the computer erroneously notifies the credit clearing house of a business customer's failure to pay his bills and injures his credit standing. Relying upon a computer to calculate steel girder specifications for a skyscraper, an engineering firm inadvertently misses an error, and the building collapses during construction. Through an error in its data processing system, a private hospital releases a patient infected with a contagious disease, and he passes on the disease to others. In each case, a lawsuit results.

Notice that these situations are of two types. In one, an operation utilizing an EDP device fails by accident and hurts people or their property. In the other, an activity not utilizing an EDP mechanism causes a harm-producing accident that might have been prevented by the use of that means. It is in the context of these types of accidents, with a myriad of variations,

that the rules of negligence law are applied to determine whether the business concern (or its insurance company) or the injured outsiders themselves shall bear the cost of the damage. Injured employees, however, usually are not covered by these rules in pressing claims against their own employers, but are assured of recovery under workmen's compensation laws in practically all cases.

LAW REQUIRES REASONABLE PRECAUTIONS

In essence, negligence law requires that persons causing harm to others through carelessness pay compensatory damages. Under it, liability is based on legal fault. It places a financial burden on persons who fail to exercise sufficient foresight to avoid accidents. As a corollary, it places no such burden on anyone whose acts cause harm but who could not have anticipated and avoided the accident. The test is whether the malefactor exercised the care that would be expected of an imaginary "reasonable man" under the same circumstances.

TEMPTATIONS TO TAKE RISKS

Although normally sound engineering or business considerations automatically insure the taking of all precautions a lawyer might recommend to prevent injury-causing breakdowns, they are not universally effective. Disruptions in operations and errors usually cannot be tolerated, even if no outsider is harmed by them. However, there may be situations where the avoidance of legal liability requires a higher standard of system or machine performance than otherwise would be sought. This might involve either the incorporation of additional control factors in the specifications of an EDP system being used or contemplated or the adoption of such a system in place of manual or other inferior means for hazard detection or avoidance. Compromises might be attractive because of the substantial cost of aiming for greater perfection. An awareness of the seriousness of the risk present in each specific case is important before a sound choice of alternatives can be made. In the following review of the legal process, an idea will be given how those risks can be assessed.

Let us consider an example of increased danger of injury from the adoption of a machine system. In the case of the damage to merchandise from improper humping, the railroad's records might disclose both the specific contents of the car and the order not to hump, but only the "do not hump" message might guide the classification device. If the messages were processed by people, however, it is likely that the inconsistency would be detected and the proper treatment would be accorded the car consistent with its contents.

There are no rules of negligence law that say in advance specifically how people must or must not act in particular situations under pain of a definite penalty for deviation. Instead, we act at our peril, always liable to be required to pay damages if a court holds that we were careless in causing harm. Hence, enforcement is accomplished by lawsuits and claims filed by affected private parties, not by the district attorney or a government regulatory agency. Since carelessness alone, in the absence of damage, is not in itself punishable by civil suits, there frequently is the temptation to gamble that no accident will occur when risks are taken.

COURTS MAKE THE LAW

Negligence law is predominantly the result of everyday human experience, not the product of legislative action. The courts developed the controlling principle, and they give it vitality by deciding the many widely diverse cases brought to them. Thus, the law really is how the courts have ruled on particular fact situations and how lawyers believe they would rule in the future.

Because the same general principle of law governs all negligence situations regardless of the means by which or the circumstances under which harm is caused, the body of law has grown right along with the evolution of society. For example, when automobiles came into use, it was applied to them, just as it was to horse and buggy drivers previously. Similarly, it will govern the utilization of EDP devices as they represent either potential causes of or means of avoiding harm. Until there is a large volume of decided cases on the new mechanisms, decisions in cases involving them will be made by drawing analogies to ostensibly comparable situations in other fields. Recall the previous example of the incorrect credit report that harmed a business customer. In an analogous case, a court declared (2),

> . . . [E]very member of this particular association is bound to know of the possible far-reaching effect which may result from placing the name of a trader on its delinquent debtor's list, and . . . every member is required to exercise great care before he sends in a name to be placed on such a list. If he does not he may make himself liable for the wrong done.

This brief recital of the basic principles of the law indicates that its true significance is to be found in the way the nonobjective standard is applied in practice. Who measures the sufficiency of foresight or the due care of a reasonable man, as the lawyers tag it, and how does he do it? The legal procedure provides some guides or clues to the scope of the test in the form of prior decisions, but it places considerable leeway in the hands of the deciding body.

JURIES DECIDE ON NEGLIGENCE

When a negligence claim gets to court, the test of liability normally is applied by a jury of laymen guided ultimately in most cases by their own experience in deciding what a reasonable man would have done. No specially qualified person may testify directly on the negligence of the defendant's acts, except in medical malpractice cases. However, the jury is not expected to decide whether negligence is present without any as-

sistance. Evidence may be introduced of precautions taken and of those available. Frequently, protective measures become more efficient and more numerous as technology develops, and the precautionary burdens of reasonable men become greater by that process. Furthermore, customary practices in a field of activity may be shown, although they should not have a conclusive effect because of the variability of fact situations. Hence, the more widely a type of protective device is used for a certain purpose, the more likely it is that it would be considered to be due care to adopt it for that purpose. But constant attention must be given to its adequacy. Blind reliance may not safely be placed on a measure just because others are foolhardy in relying on it.

Since the test of negligence is so subjective, the personal attitudes of the jury members toward the subject matter of each case as well as toward the respective litigants inevitably play an important role in the ultimate decision. In the case of EDP devices, some people may favor their use, and hence be sympathetic toward their users or critical of their nonusers, because they are considered to be modern, efficient, or infallible. Others might strongly disfavor their use out of a feeling that they displace people or are unreliable because they lack human judgment. Although these attitudes are molded by the education, age, employment history and other facets of each specific person, they also are influenced in large part by the tenor of discussions of the new technology in the press and the treatment of employees affected by the introduction of the systems.

EDP machines have not yet been designed to determine categorically whether specific sets of facts amount to legal negligence. And most lawyers probably hope that they never will be because, as long as liability for fault is retained, they regard the jury as a sensitive mechanism for distributing the social cost of losses through accidents. However, some undoubtedly would be intrigued by a device that could point out inconsistencies in witnesses' versions of objective physical events, such as those constituting an automobile accident.

CONTINUOUS EVALUATION OF PRECAUTIONS REQUIRED

In most cases, a jury is supposed to decide what a reasonable man would have done just prior to the accident to prevent it. EDP technology has a number of special aspects meriting mention in this connection. In the first place, the key to most systems is the program, and that is established to function for a considerable period in the future. Mistakes made in programming may not have their impact until long after. Or, changed, unanticipated operating conditions may introduce hazards into a properly designed program. Hence, caution suggests that programs be reviewed continually to insure that they will avoid accidents. Similarly, where EDP units are utilized to warn of or prevent hazards, due care in their initial selection may become carelessness if subsequently developed more efficient devices are ignored. In a dynamic field like EDP, this possibility also requires constant attention to the adequacy of protective measures taken. This is especially so because manufacturers and publishers are prone to dramatize the capabilities of new EDP developments, in that way enlarging public expectations from the devices. In fact, there is always a danger that juries may unconsciously evaluate the adequacy of precautions taken long previously in terms of current technology.

EDP ENGINEERS AND LAWYERS

This excursion into the mysteries of the law of negligence is intended to make EDP engineers aware of the importance of spotting potential legal hazards in systems being designed or operated and of the opportunities to utilize legal requirements to convince potential customers to adopt protective EDP systems. In many cases involving EDP control, they will be the first persons in a position to detect the potential for accidents. Engineers should recognize that the legal test of liability for damage is extremely subjective, in view of the procedure for its application, and is equally fluid because of the rapidly evolving technology. This makes it difficult to assess with any degree of accuracy risks confronting systems users and thus might tend to favor caution in design. By the same token, it makes it advisable for nonusers, in case of doubt, to take reasonable measures to reduce their hazard exposure which, as time goes on, frequently will be the adoption of EDP devices. Being alerted to situations with legal ramifications, EDP engineers undoubtedly will benefit substantially in the performance of their duties from competent legal advice relating to specific fact situations and reflecting current legal experience. As difficult as risk assessment is, the lawyer undoubtedly is best qualified to perform the function.

REFERENCES

(1) Freed, Roy N., "A Lawyer's Guide through the Computer Maze," *The Practical Lawyer*, November 1960, pp. 15-45.
(2) Hartman versus Hyman and Lieberman, 287 pa. 78 (1926).

A Heuristic Method of Assembly Line Balancing

by **MAURICE D. KILBRIDGE**
University of Chicago
and **LEON WESTER**
Armour Research Foundation, Chicago

THE PRINCIPLE of the division of labor when applied to the mass assembly of manufactured items takes the form of the progressive assembly line. The work is divided into individual tasks and assigned to consecutive operators on the line. As the product moves down the line each operator adds to it his share of the work. The process of apportioning the assembly work among the operators is known as "line balancing."

Although progressive assembly has been practiced for fifty years[1] in American industry, some of the basic problems associated with it have not received adequate attention. Among these is the line balancing problem which, until recently, was not formulated analytically. Trial and error and enumeration techniques have been relied upon, with the result that industry wastes an estimated four to ten percent of operators' time on assembly lines through unequal work assignments.

In the past five years several analytical studies of line balancing have appeared in the literature (1), (2), (3), (4), (5), (6), (7), (8), (9). The systems proposed in these studies range from rigorous mathematical techniques to approximation routines written for digital computers. Those presenting computer programs are based on arbitrarily zoned assembly lines. Although all the proposed methods have merits, none has the advantage of simplicity. Either the method requires a computer, or only a person of considerable mathematical competence can cope with it.

The problem is approached here with emphasis on the applicability of the method to existing conditions in manufacturing plants where computers and mathematicians are not always available. An algorithmic solution is desirable, but, as frequently happens in combinatorial problems, an algorithm becomes intractable as the problem size increases. Therefore a heuristic method of line balancing was devised which requires logical analysis of problem data. It is presented here with emphasis on procedure rather than on computational details.

[1] The first progressive assembly line was started at the Ford Highland Park Plant in 1913, and Henry Ford is properly credited with its invention. He combined the long known principles of the division of labor, the fabrication of interchangeable parts, and the movement of product past fixed work stations into the concept of assembly as a continuous process.

ASSEMBLY LINE TERMINOLOGY

A *work station* is an assigned location where a given amount of work is performed. Assembly line work stations are generally manned by one operator. However, on short runs an operator may man more than one station, and on lines of large products (aircraft, for example) work stations are frequently manned by several operators.

A *minimum rational work element* is an indivisible element of work or natural minimum unit beyond which assembly work can not be divided rationally. For example, a minimum rational element may include the following motion pattern: reach to a tool, grasp it, move it into position, perform a single task, return the tool. In practice such work elements are considered indivisible since they cannot be split between two operators without creating unnecessary work in the form of extra handling.

The *total work content* is the aggregate amount of work of the total assembly. The total work content time is the time required to perform the total work content. The *station work content* time is the time required to perform the work content of the given station. This time is also known as the operation time.

The *cycle time* is the time the product spends at each work station on the line when the line is moving at standard pace, or 100 percent efficiency. Stated in other words, the cycle time is the amount of time elapsing between successive units as they move down the line at standard pace. Extending this definition, the cycle time is the maximum operation time. The cycle time, and the pace at which the line operates, together determine the rate at which products flow from the line.

Balance delay time is the amount of idle time on the line due to the imperfect division of work between stations. Since it seems to be seldom possible to divide the work evenly between all operators on the line, those op-

erators having shorter assignments will have some idle time. This idle time is a measure of the imbalance of the line.

In practice those operators having shorter work assignments will not actually stand idle at the end of each cycle, but will work continuously at a slower pace. The effect, measured in terms of labor cost, however, is the same as if they were idle part of the time and working at a faster pace the rest of the time.

If all of the station work content times were equal, there would be no imbalance. The degree or percent of imbalance, simply called "balance delay," is the ratio between the average idle time at the stations and the maximum operation time. Stated otherwise, balance delay is the ratio between the total idle time and the total time spent by the product in moving from the beginning to the end of the line.

Balancing restrictions are constraints imposed on the order or time sequence in which work elements can be performed. They are of three types:

1. Technological restrictions on the order of assembly of components or piece parts.
2. Restrictions imposed by fixed facilities or machines on the line.
3. Restrictions of position, where position refers to the operator or operator-.

THEORETICAL ANALYSIS OF BALANCE DELAY

Balance delay in percent is defined in mathematical terms as the ratio

$$d = 100\,\frac{c - \bar{c}}{c},$$

where c is the maximum operation time or cycle time, and $\bar{c}$ is the average operation time. If the assembly line is manned by n operators (one at each of n work stations), then d can also be written as

$$d = 100\,\frac{nc - n\bar{c}}{nc} = 100\,\frac{nc - \Sigma_i t_i}{nc}, \quad (nc - \Sigma_i t_i \geq 0),$$

where t_i $(i = 1, 2, \ldots, k)$, is the duration of the ith work element in the distribution and $\Sigma_i t_i$ is the total work content time.

It is important to note that for a given cycle time, c, and a given total work content time, $\Sigma_i t_i$, there exists a minimum number of operators, $n_{\min}$. The minimum balance delay in percent is defined as

$$d_{\min} = 100\,\frac{n_{\min}c - \Sigma_i t_i}{n_{\min}c}$$

and is a function of cycle time, c. This function, called the balance delay function, can be plotted on a graph. Since the definition of $d_{\min}$ is unequivocal, the subscript can be dropped, and

$$d = 100\,\frac{nc - \Sigma_i t_i}{nc}$$

will have the connotation of $d_{\min}$.

The range of possible cycle times, c, is

$$t_{\max} \leq c \leq \Sigma_i t_i.$$

That is, the cycle time, c, must equal or exceed the maximum element, $t_{\max}$, in the work element distribution, but cannot exceed the total work content time, $\Sigma_i t_i$. The lower bound of c follows from the definition of cycle time. The upper bound is based on practical considerations. There is no sense in allowing the cycle time to increase beyond the total work content time. For computational convenience it will be assumed that the durations of work elements t_i, are expressed in integers, so that $\Sigma_i t_i$ is also an integer.

A simple but useful theorem in line balancing theory can now be stated as follows: A necessary but not sufficient condition for perfect balance (or zero delay) is that

$$nc - \Sigma_i t_i = 0,$$

where n (the number of work stations) is an integer. This implies that $\Sigma_i t_i$ must be divisible by c, for otherwise $n = \Sigma_i t_i / c$ is not an integer.

The condition is necessary, because if balance delay is zero, then $nc - \Sigma_i t_i = 0$, and $\Sigma_i t_i / c = n$ is an integer (by assumption).

It is not sufficient because situations exist for which, although $\Sigma_i t_i / c$ is an integer, it is not possible to assign the given elements to the n work stations.

In order to find all possible zero points of the balance delay function, $\Sigma_i t_i$ must be divided by all the c's, $(t_{\max} \leq c \leq \Sigma_i t_i)$, respectively, for which the quotient $\Sigma_i t_i / c$ is an integer, n. Then if, for a given cycle time, c, all the work elements in the distribution can be fitted into the n work stations or intervals of duration c each, while heeding sequential restrictions, perfect balance has been attained for that particular case. Otherwise, the number, n, of work stations must be increased by the least integer required to achieve balance, and then the balance is not perfect $(d > 0)$. For all other cycle times, it is known a priori that the balance delay is not zero. To find the corresponding balance delay value, the number of work stations is chosen as an integer exceeding $\Sigma_i t_i / c$ by the minimum amount required to fit the elements into the n intervals.

Since the work element times are expressed in integers, the cycle times are integers also, and the balance delay function, $d = f(c)$, is a discrete function. However, it will be convenient to plot its graph by connecting consecutive points of the function with straight lines. The graph will thus have the appearance of continuity and will emphasize features and trends which might otherwise be overlooked.

In general, the balance delay function thus derived has the shape of a zigzag line reaching the cycle time axis wherever a zero point occurs. Figure 1 shows a portion of a balance delay curve for an assembly line. The curve is drawn for cycle times of from 0.80 minutes to 1.20 minutes. The figure shows that within this range,

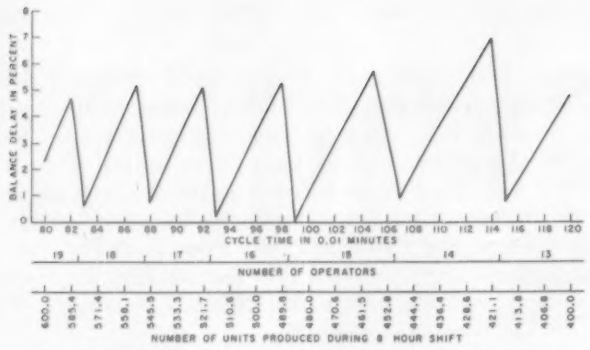


FIGURE 1. Typical Balance Delay Function, $80 \leq c \leq 120$.

zero balance delay is attainable at a cycle time of 0.99 minute. The cycle time actually in use on this line was 0.94 minute, which, according to Figure 1 would entail a minimum balance delay of about 1.25 percent. The balance delay actually experienced on the line was 5.0 percent.

The balance delay function tells what cycle time to select for a given distribution of work elements and a given number of operators. Since balance delay is to be minimized, a cycle time should be chosen which, in conjunction with the given number of operators, insures the least balance delay. These points may be found for all values of n at the local minima of the balance delay function.

Another question that can be answered from a glance at the balance delay function is how many units, N, can be produced most economically on the assembly line in a given time interval, say, during an eight-hour shift, with n operators, or conversely, what cycle time should be used in order to produce N units with n operators.

Since there is a one-to-one correspondence between the cycle time, c, and the number of units produced, N, during a given time of duration T ($N = \frac{T}{c}$), a horizontal scale indicative of N can be added to the graph of the balance delay function. For example, Figure 1 indicates that about 461 units can be produced in eight hours with 15 operators at a cycle time of 1.04 minutes with a minimum balance delay of 4.75 percent. The figure also shows that 15 operators can produce in eight hours 485 units at a cycle time of 0.99 minute with zero balance delay. This implies that production of 461 units will cost as much as that of 485 units. Thus management has the two least cost alternatives of choosing a production rate of 485 units per 8 hour shift at a cycle time of 0.99 minute, or of producing 461 units at this same cycle time in about a 7½ hour shift.

THE LINE BALANCING METHOD

To describe the heuristic method of line balancing an illustration is given which is not drawn from industry. Other examples are available; however, they involve technological complexities which have no direct bearing on the method. The illustration is that first suggested by Salveson (6) of dressing in the morning, that is, of assembling one's clothes. The example has essentially the same properties as many industrial jobs, and therefore is not trivial. The work can be divided into a given number of operators of equal duration while heeding necessary sequential restrictions. Each operation consists of one or more irreducible work elements combined in such a way as to equalize the time required for each operation.

The illustration is described in the precedence diagram of Figure 2. The numbers inside the circles identify the various elements of work and the numbers outside the circles refer to the corresponding time durations. The arrows indicate precedence relations. The elements and their time durations are shown in Table 1. Thus, element 1 of duration 9 must precede element 3 of duration 10, and element 7 of duration 13. Element 3 must precede element 5 of duration 17 and element 7 must precede element 14 of duration 22, and so forth.

The precedence diagram is drawn so that the assembly progresses from left to right, each element being as far left as possible at the start of the procedure. Precedence diagrams are constructed as described by Jackson (4). First, in column I of the diagram are listed all work elements which need not follow any work elements. Then, in column K ($K \geq$ II) are entered all those work elements which must follow work elements already on the diagram. Finally, arrows are drawn from work elements in column $K - 1$ to work elements in column K which must follow them. This procedure is repeated, replacing column $K - 1$ by columns $K - 2, \ldots, 1$, successively, except that no arrow is drawn from one work element to another if it is possible to follow arrows already drawn from the first work element to the second.

The problem of line balancing is to achieve the least possible balance delay for given conditions. Thus, for a

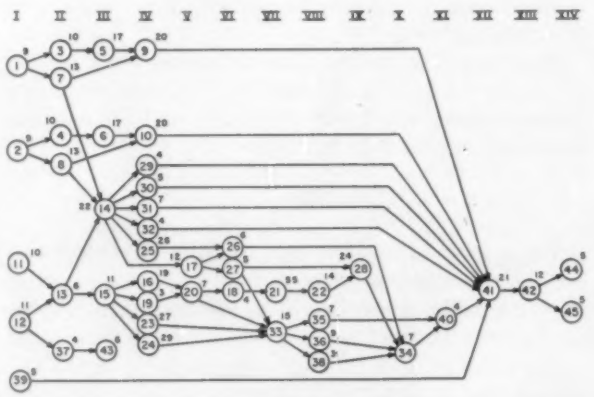


FIGURE 2. Precedence Diagram for Work Elements in "Assembling Clothes" (Unbalanced Case).

TABLE 1

Work Elements in "Assembling Clothes"

Element No.	Description	Time (in 0.01min.)
1.	Pick up and put on left sock	9
2.	Pick up and put on right sock	9
3.	Pick up and put on left shoe	10
4.	Pick up and put on right shoe	10
5.	Tie left shoe lace	17
6.	Tie right shoe lace	17
7.	Pick up, put on, and attach left garter	13
8.	Pick up, put on, and attach right garter	13
9.	Pick up, put on left spat	20
10.	Pick up, put on right spat	20
11.	Pick up and put on undershorts	10
12.	Pick up and put on undershirt	11
13.	Tuck in undershirt	6
14.	Pick up ane put on trousers	22
15.	Pick up and put on shirt	11
16.	Button 5 buttons	19
17.	Tuck in shirt	12
18.	Button shirt neck button	4
19.	Turn up collar	3
20.	Pick up and put on tie, turn down collar	7
21.	Tie tie	55
22.	Pick up and put on tie clip	14
23.	Fold back left cuff—pick up and put on left cuff link	27
24.	Fold back right cuff—pick up and put on right cuff link	29
25.	Pick up and put on belt	26
26.	Buckle belt	6
27.	Pick up and put on vest	5
28.	Button vest (6 buttons)	24
29.	Pick up and place handkerchief	4
30.	Pick up and place wallet	5
31.	Pick up and place small change	7
32.	Pick up and place keys	4
33.	Pick up and put on suit jacket	15
34.	Button suit jacket	7
35.	Pick up and place pocket handkerchief	7
36.	Pick up and place fountain pen	9
37.	Pick up and place glasses	4
38.	Pick up and place glass case	3
39.	Pick up and put on wrist watch	5
40.	Pick up and put on scarf	4
41.	Pick up and put on top coat	21
42.	Button top coat	12
43.	Pick up and put on hat	6
44.	Pick up and put on left glove	5
45.	Pick up and put on right glove	5
	Total work content ($\Sigma_i t_i$)	552

specified distribution of elements and restrictions on their ordering, and a given cycle time, c, one may be required to find the minimum number, n, of operators to perform the task; or, for a given number, n, of operators, one may wish to determine the shortest cycle time, c. If neither c nor n is given, it is necessary to determine the value, or values, of c and n for which balance delay is zero. This is the procedure followed below.

To determine the cycle times for which $\Sigma_i t_i/c$ is an integer, it is convenient to write $\Sigma_i t_i$ as a product of prime numbers, i.e.

$$\Sigma_i t_i = 552 = 2 \times 2 \times 2 \times 3 \times 23.$$

Since $55 \leq c \leq 552$, it is easily seen that the quotient $\Sigma_i t_i/c$ is an integer for

$$c_1 = 2 \times 2 \times 2 \times 3 \times 23 = 552$$
$$c_2 = 2 \times 2 \times 3 \times 23 = 276$$
$$c_3 = 2 \times 2 \times 2 \times 23 = 184$$
$$c_4 = 2 \times 3 \times 23 = 138$$
$$c_5 = 2 \times 2 \times 23 = 92$$
$$c_6 = 3 \times 23 = 69$$

Hence, perfect balance can possibly be achieved with

$$n_1 = \frac{\Sigma_i t_i}{c_1} = \frac{552}{552} = 1 \text{ station (trivial case)}$$

$$n_2 = \frac{\Sigma_i t_i}{c_2} = \frac{552}{276} = 2 \text{ stations}$$

$$n_3 = \frac{\Sigma_i t_i}{c_3} = \frac{552}{184} = 3 \text{ stations}$$

$$n_4 = \frac{\Sigma_i t_i}{c_4} = \frac{552}{138} = 4 \text{ stations}$$

$$n_5 = \frac{\Sigma_i t_i}{c_5} = \frac{552}{92} = 6 \text{ stations}$$

$$n_6 = \frac{\Sigma_i t_i}{c_6} = \frac{552}{69} = 8 \text{ stations}$$

The question now is whether perfect balance is actually attainable for the above six cycle times.

The diagram of Figure 2 shows that elements in each vertical column are mutually independent (they are not connected by arrows), and therefore can be permuted among themselves in any work sequence without violating restrictions on precedence relations. Furthermore it can be seen that many elements can be moved laterally from their columns to positions to their right without disturbing the precedence restrictions. For instance, element No. 39 can be moved from column I to column II, III, . . . , or XI, and element No. 3 can also be moved to the right, provided that elements No. 5 and No. 9 are moved simultaneously in order to preserve the precedence relations as required. Thus, it is evident that there exists a large number of topologically equivalent diagrams which satisfy the same sequential restrictions. The flexibility of the diagram depends on the number of restrictions, but in most industrial cases this number is moderate, affecting the flexibility of the diagram only slightly.

The above two properties of elements in the precedence diagram—permutability within columns and lateral transferability—are exploited in the attempt to achieve optimum balance. Other properties which offer additional opportunities will not be discussed here since in most cases they are of minor interest.

Next in the line balancing procedure is the construction of a table containing detailed information about each element taken from successive columns of the precedence

TABLE 2

Tabular Representation of Precedence Diagram for Work Elements in "Assembling Clothes"

(A) Column Number of Diagram	(B) Element Identification Number	(C) Remarks	(D) Element Time Duration t_i	(E) Sum of Time Durations	(F) Cumulative Time Sums
I	1		9		
	2		9		
	11		10		
	12		11		
	39	→ II, . . . , XI	5	44	44
II	3 (w. 5, 9)	→ III, . . . , IX	10		
	7		13		
	4 (w. 6, 10)	→ III, . . . , IX	10		
	8		13		
	13		6		
	37 (w. 43)	→ III, . . . , XIII	4	56	100
III	5 (w. 9)	→ IV, . . . , X	17		
	6 (w. 10)	→ IV, . . . , X	17		
	14		22		
	15		11		
	43	→ IV, . . . , XIV	6	73	173
IV	9	→ V, . . . , XI	20		
	10	→ V, . . . , XI	20		
	29	→ V, . . . , XI	4		
	30	→ V, . . . , XI	5		
	31	→ V, . . . , XI	7		
	32	→ V, . . . , XI	4		
	25	→ V+	26		
	16		19		
	19		3		
	23	→ V, VI	27		
	24	→ V, VI	29	164	337
V	17		12		
	20		7	19	356
VI	26	→ VII, . . . , IX	6		
	27		5		
	18		4	15	371
VII	21		55		
	33 (w. 35, 36, 38)	→ VIII	15	70	441
VIII	22		14		
	35	→ IX, X	7		
	36	→ IX	9		
	38	→ IX	3	33	474
IX	28		24	24	498
X	34		7	7	505
XI	40		4	4	509
XII	41		21	21	530
XIII	42		12	12	542
XIV	44		5		
	45		5	10	552

diagram. Thus column A of Table 2 shows the column number of the diagram, and column B indicates the element identification number. Column C is reserved for remarks concerning the transferability of elements. For instance, it is indicated under "Remarks" that element No. 39 can be moved from column I to columns II, III, . . . , up to column XI. It is also stated that element No. 4 can be moved from columns II to columns III, IV, . . . , up to column IX provided elements Nos. 6 and 10 are displaced accordingly, and so forth. Column D gives the time duration for each element, column E, the sum of time durations for each column in the diagram, and column F the cumulative time sums.

Although perfect line balance was achieved for all six values of c (552, 276, 184, 138, 92, 69), the heuristic method will be demonstrated only for $c_3 = 184$.

Example for $c_3 = 184$.

If the work can be balanced perfectly for $c_3 = 184$, then the number of stations is

$$n_3 = \frac{\Sigma_i t_i}{c_3} = \frac{552}{184} = 3.$$

Column F of Table 2 indicates that if time elements can be arranged in a proper sequence, the cumulative sum will add to 184 within column IV. Is it possible to permute the elements in column IV, so that this number (184) is actually obtained? A cursory examination shows

TABLE 3

Modified Table 2 After Assignment of Work Elements to Station 1 Only ($t_3 = 184$)

(A) Column Number of Diagram	(B) Element Identification Number	(C) Remarks	(D) Element Time Duration, t_i	(E) Sum of Time Durations	(F) Cumulative Time Sums	
I	1		9			Station 1
	2		9			
	11		10			
	12		11			
	39		5			
II	3		10			
	7		13			
	4		10			
	8		13			
	13		6			
	37		4			
III	5		17			
	6		17			
	14		22			
	15		11			
	43		6			
IV	31		7			
	32		4	184	184	
	9	→ V, . . . , XI	20			Unassigned Work
	10	→ V, . . . , XI	20			
	29	→ V, . . . , XI	4			
	30	→ V, . . . , XI	5			
	25 (w. 26)	→ V+	26			
	16		19			
	19		3			
	23	→ V, VI	27			
	24	→ V, VI	29	153	337	
V	17		12			
	20		7	19	356	
VI	26	→ VII, . . . , IX	6			
	27		5			
	18		4	15	371	
VII	21		55			
	33 (w. 35, 36, 38)	→ VIII	15	70	441	
VIII	22		14			
	35	→ IX, X	7			
	36	→ IX	9			
	38	→ IX	3	33	474	
IX	28		24	24	498	
X	34		7	7	505	
XI	40		4	4	509	
XII	41		21	21	530	
XIII	42		12	12	542	
XIV	44		5			
	45		5	10	552	

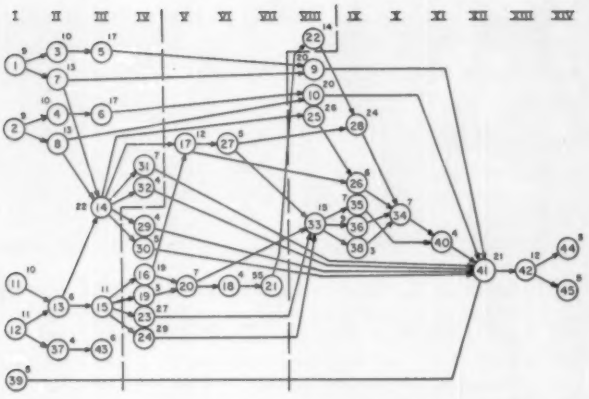


FIGURE 3. Precedence Diagram for Work Elements in "Assembling Clothes" (Work Balanced for Three Stations).

that if elements Nos. 31 and 32 are moved to the top of column IV, the cumulative sum of time durations up to and including element No. 32 is exactly equal to 184. Hence, one assigns work elements Nos. 1, 2, . . . , 39, 3, . . . , 37, 5, . . . , 43, 31, 32, in that order, to the first station (see Table 3).

The work sequence for station one is thus: 1. pick up and put on left sock; 2. pick up and put on right sock; 11. pick up and put on undershorts; 12. pick up and put on undershirt; 39. pick up and put on wrist watch; 3. pick up and put on left shoe; 7. pick up, put on and attach left garter; 4. pick up and put on right shoe; 8. pick up, put on and attach right garter; 13. tuck in undershirt; 37. pick up and place glasses; 5. tie left shoe lace; 6. tie right shoe lace; 14. pick up and put on trousers; 15. pick up and put on shirt; 43. pick up and put on hat; 31. pick up and place small change; 32. pick up and place keys. Although this may seem to be a curious dressing sequence, it is obviously possible, in that it does not contradict any of the sequencing restrictions.

Referring to column F of Table 3, it is evident that the cumulative sum of 368 (i.e. 184 + 184) will occur within column VI of the diagram, if the elements can be ordered suitably. However, it is not possible to simply permute the elements in that column to arrive at the total of 368, and it is now necessary to resort to another stratagem. By moving elements in the diagram from their respective columns to positions in succeeding columns, the desired result is achieved.

Thus it is convenient to make the following changes:

Move element No. 9 from column IV to column VIII,
Move element No. 10 from column IV to column VIII,
Move element No. 25 from column IV to column VIII,
Move element No. 33 from column VII to column VIII,
Move element No. 26 from column VI to column IX,
Move element No. 35 from column VIII to column IX,
Move element No. 36 from column VIII to column IX,
Move element No. 38 from column VIII to column IX.

After the modification of Table 3, the cumulative sum of time durations equaling 368 falls into column VIII. Thus, elements Nos. 29, . . . , 24, 17, 20. 27, 28, 21, 22, in that order, are assigned to the second station, and the remaining elements Nos. 9 through 45, as indicated in Table 4, are assigned to the third station. It is thus demonstrated that perfect balance can be achieved with a cycle time $c_3 = 184$. The precedence diagram showing the resulting arrangement of elements is given in Figure 3.

The heuristic method of line balancing was demonstrated for a cycle time with promise of potential zero balance delay. This was done because perfect balancing cases are the most difficult to solve. This is true because it is easier to pack the work elements into cycle times when it is not required that the time intervals be completely filled. For all cycle times other than the six values derived, it is known a priori that perfect balance is unattainable. To find the resulting balance delay the number of stations, n, is chosen as an integer exceeding

TABLE 4

Modified Table 3 After Assignment of Work Elements to All Three Stations ($c_3 = 184$)

(A) Column Number of Diagram	(B) Element Identification Number	(C) Remarks	(D) Element Time Duration, t_i	(E) Sum of Time Durations	(F) Cumulative Time Sums	
I	1		9			Station 1
	2		9			
	11		10			
	12		11			
	39		5			
II	3		10			
	7		13			
	4		10			
	8		13			
	13		6			
	37		4			
III	5		17			
	6		17			
	14		22			
	15		11			
	43		6			
IV	31		7			
	32		4	184	184	
	29		4			Station 2
	30		5			
	16		19			
	19		3			
	23		27			
	24		29			
V	17		12			
	20		7			
VI	27		5			
	18		4			
VII	21		55			
VIII	22		14	184	368	
	9		20			Station 3
	10		20			
	25		26			
	33		15			
IX	28		24			
	26		6			
	35		7			
	36		9			
	38		3			
X	34		7			
XI	40		4			
XII	41		21			
XIII	42		12			
XIV	44		5			
	45		5	184	552	

$\Sigma_i t_i/c$ by the minimum amount required to pack the elements into these n stations. If balance can be attained with n being the smallest integer larger than $\Sigma_i t_i/c$, optimality is assured. Otherwise care and judgment must be exercised before the solution can be labeled "optimum."

GENERAL OBSERVATIONS REGARDING THE HEURISTIC METHOD

The following generalizations and suggestions may prove helpful in applying the heuristic method.

1. Permutability within columns is used to facilitate the selection of elements of the length desired for optimum packing of the work stations. Lateral transferability helps to deploy the work elements along the stations of the assembly line so they can be used where they best serve the packing solution.

2. Generally the solutions are not unique. Elements assigned to a station, which belong after the assignment is made in one column of the precedence diagram, can generally be permuted within the column. This allows the line supervisor some leeway to alter the sequence of work elements without disturbing optimum balance.

3. Long time elements are best disposed of first, if possible. Thus, if there is a choice between the assignment of an element of duration, say, 20, and the assignment of two elements of duration, say, 10 each, assign the larger element first. Small elements are saved for ease of manipulation at the end of the line.

The situation is analogous to that of a paymaster dispensing the week's earnings in cash. He will count out the largest bills first. Thus, if the amount to be paid a worker is $77, the paymaster will give three $20 bills first, then one $10 bill, one $5 bill, and two $1 bills, in that order.

4. When moving elements laterally, the move is best made only as far to the right as necessary to allow a sufficient choice of elements for the work station being considered.

CONCLUSIONS

The proposed method of assembly line balancing is not a mere mechanical procedure, since judgment and intuition must be used to derive a meaningful solution. However, the procedure is simple and can be used by production engineers without difficulty. Optimality is usually assured when the ordering restrictions on the work elements are of a technological nature only. In a few industrial cases where the sequential restrictions governing the elements are stringent, caution must be used in labeling the solution "optimum." If, in addition to technological restrictions, the constraints are positional or involve fixed plant facilities, such as overhead cranes, testing booths or other immovable installations, the work elements must be grouped into subdistributions. The consideration of these cases is beyond the scope of this presentation.

The heuristic method is an improvement over the trial and error methods traditionally used in assembly line balancing. Changes in model or in production processes can be made without creating difficult rebalancing work. The heuristic method generally provides a solution which is not unique, thus permitting the line supervisor to choose that solution which minimizes balance delay and also satisfies secondary objectives.

The method can be applied in any industry using progressive assembly techniques. It has been used successfully in the electronics and home appliance industries.

REFERENCES

(1) Bryton, B., "Balancing of a Continuous Production Line," unpublished M.S. Thesis, Northwestern University, 1954.

(2) Burgeson, J. W., and Daum, T. E., *Production Line Balancing*, File Number 10.3.002, International Business Machines Corporation, Akron, Ohio, 1958, 62 pp.

(3) Hoffman, T. R., "Permutations and Precedence Matrices with Automatic Computer Applications to Industrial Problems," unpublished Ph.D. Thesis, University of Wisconsin, 1959.

(4) Jackson, J. R., "A Computing Procedure for a Line Balancing Problem," *Management Science*, 3 (1956), pp. 261–271.

(5) Mitchell, J., "A Computational Procedure for Balancing Zoned Assembly Lines," *Research Report No.* 6-94801-1-R3, Westinghouse Research Laboratories, Pittsburgh, 1957, 11 pp.

(6) Salveson, M. E., "The Assembly Line Balancing Problem," *The Journal of Industrial Engineering*, 3 (1955), pp. 18–25.

(7) Tonge, F. M., "Summary of a Heuristic Line Balancing Procedure," *The RAND Corporation*, T-1799, September 1959.

(8) Tonge, F. M., "A Heuristic Program of Assembly Line Balancing," *The RAND Corporation*, p. 193, May 1960.

(9) Tonge, F. M., "Summary of a Heuristic Line Balancing Procedure," *Management Science*, October 1960, pp. 21–39.

SPECIAL PROJECTS INDUSTRIAL ENGINEER

Leading midwest appliance manufacturer has opening for high calibre Industrial Engineer. Work involves capital budget studies, economic analyses, operations analysis. Minimum of 4 years experience. Prefer MBA, 26-38. Excellent salary, fringe benefits, living conditions, and opportunity for growth. Relocation expenses will be arranged.

Reply to: Box F

Journal of Industrial Engineering
A. French Building
225 North Avenue, N.W.
Atlanta 13, Georgia

PRESIDENT'S COMMENTS . . .

by **JACK F. JERICHO**

President of the American Institute of Industrial Engineers, 1961-62

Acceptance Speech as President of the American Institute of Industrial Engineers[1]

I AM GRATEFUL to have the opportunity to serve as your president during the coming year. This opportunity is unquestionably the top thrill of my life. Being elected to the presidency of the American Institute of Industrial Engineers is certainly a heartwarming honor. At the same time, leadership of an organization such as ours carries with it responsibilities which will be rewarding, challenging, and even frustrating at times. The president must face many challenges from the members, the chapters, the universities, manufacturing and service industries, other societies, and government. I accept the responsibilities vested in me with sincere humility. I will do my best to graciously accept the joys as well as the many challenges ahead.

As we all realize, the profession of Industrial Engineering has been changing rapidly during the past decade and will continue to change in the years ahead. The stature and acceptance of Industrial Engineering in the engineering world has been growing by leaps and bounds. But, gray clouds have been appearing on the horizon. These clouds have appeared in many ways. In some quarters, we are accused of being too narrow in our thinking. We are also accused of not developing ourselves properly to meet the complex problems of the business world. Some even suggest we need to change our name.

Perhaps these gray clouds are true to some degree; however, when we examine the significant progress in broadening the scope of Industrial Engineering in many successful companies, as well as the continuing improvements to the Industrial Engineering curricula in many of our leading universities, we should all be proud and encouraged.

At the same time, we must recognize that being jubilant over our past successes will not make the gray clouds "just blow away." In other words, we cannot afford to stand still. We must go forward vigorously with intensified dedication in several ways:

- We must continue to develop ourselves professionally.
- We must broaden our efforts to tell the world what Industrial Engineering truly is.
- We must convince more managements what can be done by adopting the new scope of Industrial Engineering.
- We must be sure that we are ready to meet the new demands our managements will place on us as they better understand our role.
- We must use our keenest insight and wisdom in directing the future course of our profession.
- We must revitalize our profit orientation and direct more of our efforts to help our managements retard some of the current downward trends of profit.
- We must continue to work closely with the universities to make sure that the educational background being given to the future Industrial Engineers is proper to meet the needs of tomorrow.
- We must even be prepared to change our name if this is appropriate.

All of these efforts, however, should be undertaken only after careful, objective study. The long range consequences are too important to be influenced by subjective eloquence and emotionalism.

Against this general framework of where we stand today and where we should be going, let's examine some of the specific challenges facing the institute officers, the chapter officers, the members, and some of the challenges shared by all of us.

Within the institute, we have two types of challenges, those at the headquarters level and those at the chapter or member level. At the headquarters level the basic challenge is that we have unhappy, or dissatisfied, members. Some of this dissatisfaction is certainly justified and we must face the challenge of correcting this situation. Some of the dissatisfaction is not justified and,

[1] Presented: Sheraton-Cadillac Hotel, Detroit, Michigan, Saturday, May 13, 1961.

here, we need to correct these cases through improved communications or other methods. For some time, many of you have expressed varying degrees of dissatisfaction with the services provided by our headquarters. During recent weeks, an Industrial Engineering Taskforce has been working closely with our headquarters' staff to define and solve the current problems which exist in the operation of our New York office. One of the objectives of my administration will be to bend every effort to provide sound and expeditious service from our headquarters and to make sure that the philosophies and approaches of Industrial Engineering are being put to use at all times. It is the fond hope of all of us that the move into the new United Engineering Center will help us achieve this objective.

Many of you are unhappy because your managements are not fully aware of what Industrial Engineering could do for them. This attitude is expressed in the increasing number of requests being received by the senior officers in the institute to find ways and means to tell top management about the new horizons of Industrial Engineering. In this respect, we must recognize that the best way of convincing our managements to use our services is to produce results. In the long run, there is no better method. We must use initiative, we must probe into new areas, we must produce, and we must sell ourselves and our products on an individual basis. At the same time, doing these things is much more difficult than saying them and, to some extent, the institute can help in these efforts—providing you set the stage and are ready for help. I am pleased to advise all of you that concrete action will be taken during the next several months. Alex Rathe has already made plans to set up a series of informal luncheons and meetings with presidents and vice presidents of many corporations throughout the country to discuss modern Industrial Engineering and what it can do for them. In these discussions, Alex also plans to explore managements' image of us and what they think we need to do to better serve them. In addition to this action, a plan is being developed to have each institute past president meet personally with at least two company presidents during the next year to tell our story. We hope this is only the beginning of a continued effort to influence management.

Turning to a different area, for some time many of you have been clamoring for an effective and dynamic public relations program about Industrial Engineering, both on a local basis and a national basis. Many of you may be aware of the television programs held in Philadelphia during the past year about Industrial Engineering. Other chapters, such as Fort Wayne and Milwaukee, have made outstanding contributions in developing films and television programs about Industrial Engineering. Most of you have now seen samples of the new Public Relations Manual which shortly will be distributed to every chapter in the country. This is a start in this area.

To assist in community services, as contrasted with public relations, an Institute Chairman of Community Services was established last year. Naturally, the first year's effort has been spent in developing policies and in finding ways and means to set up an effective communications network so that all of the chapters can learn from each other. In the not too distant future, every chapter will be receiving community service tools which will help perform an even more effective job in this area.

To further our efforts in public relations, some chapters have volunteered to prepare articles for outstanding magazines, such as *Harvard Business Review*, *Fortune*, and *Business Week*. We must all recognize that it will take considerable effort to accomplish this kind of publicity but the institute officers pledge to you that we will not relax our efforts until we have accomplished this objective.

Another of our challenges is associated with the educational field. Often in the past, many of you have been very curious as to how we can be sure that Industrial Engineering curricula in the universities are properly inspected and are being constantly improved, to meet the dynamic needs of industry, service organizations, and our government. As many of you know, the Engineers Council for Professional Development, often called the ECPD, inspects and accredits all engineering curricula in the United States. This council obtains its inspectors for Industrial Engineering curricula through the AIIE. Our Education Committee and the ECPD Affairs Committee work very closely in selecting and training the men to carry out these inspections and, at the moment, these two committees are busily reviewing the criteria presently used for accreditation of Industrial Engineering schools to make sure that curricula are keeping up with the jet age.

Even though these activities have been fruitful, many of us feel the AIIE could perform more effectively by being a member of ECPD. This is an objective which can be fulfilled only with your help. To be considered for membership in the Engineers Council for Professional Development, the AIIE must have at least 5,000 individuals classified as members. Associates, affiliates, and honorary members do not count for this purpose—only members. This classification, as most of you will recall, is the same as the former senior member classification. Today, we have only 3,600 in this category. I am confident that there are well over 1,400 associate members who are qualified to be members. I think it is a challenge and responsibility of every chapter in the country to make a concerted effort to upgrade all associates who are qualified to be members. I hope you agree that the influence we can have on Industrial Engineering curricula will be much greater if we are part of the official family of ECPD.

Another real challenge to all of us is that we have far too few top Industrial Engineers who are really inter-

ested and active in our society. There is no doubt that the talent, maturity, wisdom, and influence of many of these men could be of value to our organization. You often ask, "Why can't we do something about this?" I assure you that the institute officers, individually and collectively, plan to contact as many top Industrial Engineers in the country as possible during the coming year to bring them into our organization. But, here is another area where you and your chapter have a responsibility. Further growth of our professional stature locally will help attract more and more top Industrial Engineers. Your role in this regard is an important one.

Many times during the past two years, I have heard the comment, "Why doesn't our *Journal* print more interesting and practical articles?" I hope you will agree that considerable progress has been made in this area. I can assure you that the *Journal* staff will print articles of this type whenever they receive them. What can you do about this? I think quite a bit! Perhaps you can help more than you realize. And to assist you, an Authors' Guide will be published by the *Journal* staff this summer. This guide should make it easier for you and your associates to prepare articles for the *Journal*.

Too frequently I hear, "But we can't write practical articles because our company is afraid our competitor will learn something if the article is published." Gentlemen, I am convinced that considerable knowledge exists and can be published in a form which will not disclose company secrets and, at the same time, can be of significant mutual benefit. I challenge every Industrial Engineering manager and director in the country to share some of their pioneering efforts with others. I am sure that with a little extra effort, practical articles for our *Journal* can be increased far beyond what is being received by the *Journal* staff today.

There are some other areas where your chapters and all of the institute officers can do a little soul searching. During the recent past we have seen a rapid and healthy growth of interest in our student chapters. Simultaneously, we have watched students receive their degrees and enter the business world only to have the "oldtimers" pay little or no attention to them. It is my feeling that the senior chapters have a major responsibility to more actively seek out these young men to make them feel wanted and important, and to help them adjust to the business world and the community climate. This help is needed while they are students and should continue for several years after graduation. We must remember that the student of today is the man of tomorrow and the hope for the future. Let's do all we can to make sure he gets off on the right path and stays there. Also, let's take advantage of this opportunity to learn something ourselves.

Another challenging area is the apathetic attitude toward the election of officers for the institute. During the coming year, a very aggressive officer development program will be installed to assure the membership that fully qualified candidates to carry out the tremendous responsibilities of the American Institute of Industrial Engineers are placed on the ballot. Thus, one possible reason for this apathetic attitude will be removed. After that, your participation is needed. For the past two or three years, only 35% of the total membership has voted. I am setting a minimum objective of 65% for the election of the 1962–63 officers. Meeting this objective is a challenge to every regional vice president and chapter president in the institute and is a responsibility of every member.

I have talked about challenges and responsibilities of the institute officers, chapter officers, and, to some degree, the membership. How about the responsibilities of the many Industrial Engineering managers throughout the country? What challenges and responsibilities do they have in the further development of the profession? Perhaps there is a need for them to be more selective in hiring, to make sure that the new men who are being brought into their companies are fully qualified and really have the ability to carry out the concepts of modern Industrial Engineering. I also feel strongly that the managers in Industrial Engineering need to make sure that they are providing the proper leadership and atmosphere, so that the new men entering the profession can develop rapidly and produce real results for management.

I have attempted to explain some of the things the institute has done and will do to improve your status as a professional Industrial Engineer. I hope you will agree that our collective efforts will pay off. At the same time, I hope each of you recognize that *you* are the institute, that you share in the responsibility for our mutual progress. To paraphrase from the acceptance speech of another president last January, we might ask ourselves, "What can I do for the institute?" Obviously, there are many things. But, a prerequisite to any contribution to the institute is continuous professional development of ourselves as individuals.

Perhaps a quote from Edwin Markham illustrates what I mean:

> We are all blind until we see
> That in the human plan
> Nothing is worth the making, if
> It does not make the man.
> Why build these cities glorious
> If man unbuilded goes?
> In vain we build the world, unless
> The builder also grows.

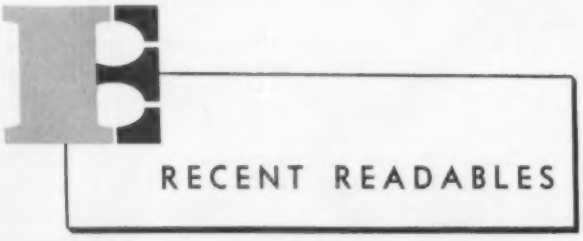
In many instances, some of us in the profession have a tendency to resent change, let ourselves get into ruts, remain close-minded, think negatively, and close the door on new ideas. We must change this situation and make sure that we are continuously open-minded and positive in our thinking at all times. We must recognize that In-

dustrial Engineering is changing and that we must change with it. In bringing about our own professional development, perhaps a brief summary of what is required in an individual for a successful career in modern Industrial Engineering would be helpful:

1. He must be a top-level research and development man, reaching into the complex management systems and the many interrelationships of these systems.
2. He should, at all times, have a good background in all of the functional aspects of business.
3. He must constantly be alert to new developments and willing to accept new ideas.
4. He must learn to deal with fundamental characteristics of problems rather than becoming an expert at using tools or, stated in a different way, he must learn to find the problem and then select the most appropriate tools for that specific problem.
5. He must always be alert to and cognizant of human behavior, broaden his understanding of people, and learn how to cope with normal resistance to change.
6. He needs to be confident and positive at all times; he must learn to create a permissive atmosphere for those with whom he works.
7. He should be completely objective at all times and always set his sights on optimizing his solutions.
8. Lastly, he should retain a sound engineering approach in his work and learn to keep the "fads" that come and go in proper perspective.

In conclusion, today's managements need what we have to offer. But, with alarming frequency, we forget that it is extremely important for us to produce results. No one single thing will help us more to get recognition for the new image of our profession than tangible results. Remember, your managers and stockholders are vitally interested in the profit and loss statement. This is where they will evaluate the real effectiveness of our efforts and determine our future.

In closing, I wish each of you a successful year, personally and professionally. Thank you for the honor of serving the American Institute of Industrial Engineers as its president. I am proud to be an Industrial Engineer and a member of the institute.



NEW PUBLICATIONS

"Electronic/Electromechanical Production"

This newsletter is the forerunner of a new magazine of the same name scheduled for monthly publication starting in November, 1961. Seven issues (March 1961 through September 1961 inclusive) of the newsletter will precede the first issue of the magazine.

This publication will be the first magazine specifically directed toward manufacturing and production engineers in the "black-box" industry. Its editorial goal "will be to keep manufacturing engineers in this industry up-to-date on the modern techniques and concepts of Industrial Engineering and the manner in which they are and can be applied to 'black-box' production lines."

For more information contact:

Harold G. Buchbinder, President
Benwill Publishing Corporation
167 Corey Road
Brookline 46, Massachusetts

"Addison-Wesley Newsletter"

A digest of what's new in educational facilities and books, published fall, winter, and spring by Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, and 10/15 Chitty Street, London W. 1, England. Sent free of charge to scientists and engineers in teaching and in industry, to bookstores, and to libraries. If you are not already receiving a personal copy, send in request to the above address.

In response to the current demand for training media in the principles of PERT/PEP critical path planning techniques, there was released recently a training presentation which introduces both the technical and the management aspects of PERT/PEP.

The presentation is based on latest theory and industry experience and consists of 36 color slides accompanied by narrative instruction material.

Material is available from:

Management Planning System Company
19919 Marine View Drive S. W.
Seattle 66, Washington

AUTOMATION*

"Providing an Engineered Environment for Modern Computers," by James F. McGovern, PLANT MANAGEMENT AND ENGINEERING, *April 1961.*

This article offers a comprehensive discussion of important considerations for investigation if your company is planning a modern computer application. The author, former manager of Plant Engineering and Maintenance, IBM Command Control Center, is well qualified in the field. Important considerations, both theoretical and practical, are presented and discussed. (*J. M. Barksdale—Ethyl Corporation*)

"Veteran Plant Made Combat Ready," by F. F. Behm, FACTORY, *March 1961.*

How a team of experienced planners were able to modernize an obsolete plant without any significant loss in production. The heart of the entire project was the installation of a plant-wide automatic conveyor system. (*I. L. Haines—Lukens Steel Company*)

COST CONTROL

"The Information Mess—Part 2," by A. B. Cummins, FACTORY, *March 1961.*

A letter advocating the need for two data systems in a manufacturing organization. The second system, designed independently of the after-the-fact financial accounting controls, must be able to cope with evolutionary rather than static forces. (*I. L. Haines—Lukens Steel Company*)

---

* *In the Recent Readables section of the March-April 1961* JOURNAL, *the article "A Special Analysis on Computers," by J. A. Eaton, was listed as being published in* MATERIALS HANDLING ENGINEERING. *This statement was in error. The article was published in the October 1960 issue of* MODERN MATERIALS HANDLING.—*Editor*

"Mathematical Models in Capital Budgeting," by James C. Hetrick, HARVARD BUSINESS REVIEW, *January-February, 1961.*

Here is a new approach to the use of operations research techniques in planning, budgeting, and other strategic areas. Direction for constructing and using a model are included. (*A. L. Friedrichs—Ethyl Corporation*)

ENGINEERING ECONOMY

"The Economic Analysis of Military Equipment Replacement," by James M. White, THE ENGINEERING ECONOMIST, *Spring, 1961.*

This paper is concerned with the economic analysis of invention applied to military preparedness. Equipment replacement policies are evaluated with an eye on technological innovation as well as obsolescence. (*J. P. Fagan—Ethyl Corporation*)

"Dynamic Industrial Engineering," by Albert G. Holyman, ADVANCED MANAGEMENT, *page 7, April 1961.*

Many companies still employing Industrial Engineers primarily as time study experts, fail to realize the potential impact of Industrial Engineering on the total management area. Dr. Holyman presents the objectives of the Industrial Engineering Department at the University of Pittsburgh in training Industrial Engineers and discusses the opportunity for growth in the field. (*J. P. Fagan —Ethyl Corporation*)

GENERAL

"Machines Trim Maintenance Tab," CHEMICAL WEEK, *February 25, 1961, pages 41–44.*

A thoroughly enlightening article on an extremely important industrial maintenance data system. An excellent example of a working installation is discussed. A sound method of accumulating and presenting maintenance performance the following day after accomplishment is discussed. Rare indeed is a system that gets speedy cost information and analysis, but the subject system of this discussion does just that. (*J. M. Barksdale—Ethyl Corporation*)

"Equipment Performance Analysis" by J. D. Quinn, MECHANICAL ENGINEERING, *January 1961, pages 43–45.*

A most interesting and practical approach to the problem of factually and quantitatively identifying reasons for, and results of, production equipment down time. Special equipment for accomplishing this is discussed. Practical problems and applications are presented. This article is a more comprehensive approach that is traditionally used in the solution of a problem which is of great concern to both maintenance and operating people in all types of industry.

"The Myth of the Psychologist," by Clarence B. Randall, DUN'S REVIEW AND MODERN INDUSTRY, *April 1961, pages 45–47.*

Mr. Randall, former Board Chairman of Inland Steel, presents a most interesting and entertaining discussion of the role of the Industrial Psychologist in industrial management.

In taking a real look at this phenomenon Mr. Randall attempts to strip away mythology from reality. He concludes that the "magic" of the psychologist is so closely allied to the art of management that it can prove a vital aid to corporate vigor and growth. (*J. M. Barksdale—Ethyl Corporation*)

OPERATIONS RESEARCH

"The Myth of the Magic Numbers," DUN'S REVIEW AND MODERN INDUSTRY, *March 1961, pages 33–35.*

A frank appraisal of the "numbers game" being played so diligently—and at times disastrously—by many otherwise highly intelligent business leaders. Innate resistance to change has driven many to refuge in ill founded statistical facts which show little more than mass resistance to change. Sometimes the fact that the normal distribution curve represents little more than the average is ignored. Statistical data can never replace the dynamic power driving our American economy forward—freedom of choice. (*J. M. Barksdale—Ethyl Corporation*)

SYSTEMS AND PROCEDURES

"Maintenance Planning and Scheduling," by Dan G. Poppe, Plant Engineer, Uranium Ore Reduction Company, PLANT ENGINEERING, *March 1961, pages 102–107.*

Mr. Poppe uses his own experience with a highly successful maintenance planning and scheduling system to show how smaller companies can benefit from well planned maintenance control systems. Complete details of his system are presented including organizational problems, functional aspects, benefits and savings and special problems involved. (*J. M. Barksdale—Ethyl Corporation*)

"Management by Objective," by Herman Limberg, THE OFFICE, *page 14, April 1961.*

This article presents the applications of the principles and techniques of systems and procedures used by the City of New York in combating the "paper octopus." The city's approach is called "Management by Objective." (*J. P. Fagan—Ethyl Corporation*)

WORK MEASUREMENT

"How to Measure Quality and Quantity of Clerical Work," Donald B. Strahlman, THE OFFICE, *February, 1961.*

Usually work measurement and quality control programs have been operated separately with no way to relate the two and arrive at an effective production index for the individual worker.

"SAM Rating Film Application," by John F. C. Close, ADVANCED MANAGEMENT, *April 1961.*

This article presents a comparison of the concept of average incentive performance of a sample of Australian time study observers with the average value for United States as "standardized" in SAM performance rating films. (*J. P. Fagan—Ethyl Corporation*)

"Universal Application of a Work Achievement Unit," by Eino O. Ilmonen, ADVANCED MANAGEMENT, *April 1961.*

The author discusses early attempts to establish a unit of work measurement and looks at the situation today along with listing the advantages and disadvantages of finding a unit to measure work. (*J. P. Fagan—Ethyl Corporation*)

"Maintenance Cost Can Be Cut," by K. W. Bennett, IRON AGE, *February 2, 1961.*

In the average plant maintenance workers are about 40% efficient. Incentive programs can be used to boost efficiency to 100% and ease automation headaches. (*J. P. Fagan—Ethyl Corporation*)

"Measuring the Immeasurable," FACTORY, *March 1961.*

An actual application of work sampling techniques in establishing standards and an incentive system. For only half the cost of the typical measurement program, an electrical parts manufacturer has installed a successful group incentive plan. (*I. L. Haines—Lukens Steel Company*)

"Indirect Labor—Our $7 Billion Opportunity," STEEL, *April 10, 1961.*

A review by leading consultants and company engineers of the situation with indirect labor—both plant and office. Various cases are cited where work measurement in such areas has resulted in productivity increases of as much as 100%. Especially timely considering the greater percentage of total payroll now going to indirect workers. (*I. L. Haines—Lukens Steel Company*)

S RICE 08430
UNIV MICROFILMS
313 N FIRST STREET
ANN ARBOR MICHIGAN

Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.
32 West Fortieth Street New York 18, New York